PHILOSOPHICAL

TRANSACTIONS

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MDCCCXLVIII.

Adjudication of the Medals of the Royal Society for the year 1848 by the President and Council.

The Copley Medal to John Couch Adams, Esq., for his "Investigations relative to the disturbances of Uranus, and for his application of the inverse problem of perturbations thereto."

The Royal Medal in the department of Astronomy, to Thomas Galloway, Esq., for his Paper "On the Proper Motion of the Solar System," published in the Philosophical Transactions for 1847.

No recommendation of the Royal Medal in the department of Physiology having been received, this Medal was awarded to Charles James Hargreave, Esq., for his Paper entitled "On the Solution of Linear Differential Equations," published in the Philosophical Transactions for 1848.

The Rumford Medal to M. V. Regnault, for his "Experiments to determine the Laws and the numerical data which enter into the calculation of Steam-Engines."

The Bakerian Lecture for 1848 was delivered by The Rev. William Whewell, D.D., F.R.S., and entitled "On the Tides of the Pacific, and on the Diurnal Inequality."

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PHILOSOPHICAL TRANSACTIONS.

XII. *Observations on some Belemnites and other Fossil Remains of Cephalopoda, discovered by Mr.* Reginald Neville Mantell, *C.E. in the Oxford Clay near Trowbridge, in Wiltshire.*

By Gideon Algernon Mantell, *Esq., LL.D., F.R.S., F.L.S.,*
Vice-President of the Geological Society.

Received March 2,—Read March 23, 1848.

THE group of argillaceous deposits of the Oolite or Jurassic formation, termed the Oxford Clay, has yielded some of the most interesting and instructive examples of the fossil remains of Cephalopoda hitherto discovered in England. Christian-Malford, in Wiltshire, is especially celebrated for the very perfect specimens of the soft parts of certain extinct forms of this class of molluscous animals; examples having been obtained in which the body and muscular tunic or mantle, the cephalic arms with their uncinated acetabula, the capsule or external tunic of the eye-ball, the ink-bag, and the phragmocone, are preserved, and in some instances but slightly displaced from their natural relative positions and connections. The remarkable fossils described in the Memoir on the Belemnite* by Professor Owen, were procured by the Marquess of Northampton, Mr. Cunnington, and Mr. Pratt, from this locality.

A branch line from the Great Western Railway to Trowbridge in Wiltshire, now in progress, in some parts passes over, and in others cuts through, the usual series of oolitic strata of that part of England; namely, the Kimmeridge Clay, Oxford Clay, Kelloway Rock, and the Great Oolite with its subordinate beds of Cornbrash, Forest Marble, Bradford Clay, &c.† My son, Mr. Reginald Neville Mantell, who is engaged on this work under the eminent engineer I. K. Brunel, Esq., availed himself of this favourable opportunity of collecting a very extensive suite of the fossils brought to light by the various cuttings and excavations required in the construction of the railway. This collection comprises many hundred specimens of the shells and

* Philosophical Transactions for 1844, p. 65.

† Wonders of Geology, 6th edition, p. 502.

other organic remains which usually abound in this division of the Oolite formation, and among them are several unique and exquisite examples of Ammonites, Belemnites, &c. Imbedded with the animal remains were large quantities of drifted wood, and stems and branches of trees: some of these specimens are in the state of bog-wood and lignite; others are transmuted into limestone, and have the original structure well-preserved. Trunks and branches of coniferous trees, from ten to twenty feet in length, and from a few inches to upwards of a foot in diameter, were abundant; a few traces of the foliage of Cycadeaceous plants, and of Araucariæ, were likewise met with.

The geological character of the beds of Oxford Clay exposed along this railway, is that of a fluvio-marine formation; that is, an accumulation of deep sea and littoral shells, promiscuously intermingled with the debris of terrestrial vegetables brought into the sea from distant lands by the agency of streams and rivers, and transported by marine currents into the bed of the ocean. It would be highly interesting, but irrelevant to my present purpose, to dwell on the geological phenomena presented by the sections laid bare by the operations of the engineer along this tract of ten or twelve miles. The great quantity of the shells of mollusks referable to species which dwell in the profound abyss of the ocean, collocated with those which can exist only in waters of moderate depths, and the intercalation of drifted trees and plants, formed a striking illustration of the nature of the bed of the ancient oolitic sea, strewn with the spoils of the land, and the exuviæ of the animals with which the waters of that ocean were densely inhabited*.

As the Oxford Clay traversed by the Trowbridge line is a continuation of the beds that were cut through at Christian-Malford, whence all the specimens of Cephalopoda collected by Mr. Buy, the well-known fossil dealer of Chippenham, were procured, my son's attention was particularly directed to the discovery of examples that would tend to elucidate the nature of the soft parts of the animal to which the Belemnite belonged; for notwithstanding the memoir above referred to, doubts were entertained by several competent observers as to the validity of the arguments which led Professor Owen to assign the fossil Cephalopod, termed *Belemnoteuthis antiquus* by the late Mr. Channing Pearce, and described by him in 1842†, to the same genus as the true Belemnite, and to the species named *B. Owenii* by Mr. Pratt.

Care was therefore taken to remove, when practicable, the Belemnites, Ammonites, &c. with a large portion of the surrounding clay; and this, when hardened by drying,

* My son's collection comprises very fine specimens of *Ammonites Königi, A. Calloviensis, A. sublævis, A. athleta*, &c.; beautiful examples of a boat-like ammonite with a sharp keel, *A. Chamusseti*; a large depressed ammonite with a flat back and a single row of nodular tubercles on the wreaths; several kinds of *Nautilus*; numerous small shells of the genera *Rostellaria, Terebra, Turritella, Trochus*, &c.; *Ostrea deltoidea, Gryphæa dilatata, Terebratula*, &c.; bones of *Ichthyosauri, Plesiosauri, Teleosauri, Cetiosauri*, &c.; and a few scales and teeth of fishes.

† Geological Proceedings for 1842, vol. ii. p. 593; but not referred to in Professor Owen's memoir.

was diligently examined to ascertain whether there were any remains, or traces of the imprints, of the soft and perishable parts, of the bodies of the original animals. Although these researches were not rewarded by the discovery of any good examples of the muscular tunic, arms, &c. of the Cephalopoda, whose hard and durable relics are scattered in profusion through the strata, there are in the collection my son transmitted to me, a few specimens which present characters hitherto unobserved, or at least unnoticed, by any author, and which appear to me of sufficient importance to be placed on record, as interesting additions to our knowledge of the structure of the animal of the Belemnite.

In the following remarks I shall restrict myself to the description of the fossils, of which accurate figures by Mr. Joseph Dinkel, executed under my immediate inspection, are subjoined; and the bearing of the facts described on the still mooted question as to whether the Belemnoteuthis and the Belemnite belong to the same genus; in other words, whether the soft parts of Cephalopoda found in the Oxford Clay of Wiltshire, and figured and described by Mr. Channing Pearce, Professor Owen, and Mr. Cunnington, belong to the Belemnites geologically associated with them, but with which they have never yet been found in organic connection.

The late Mr. Channing Pearce, whose early death every British palæontologist must deeply regret, was the first who noticed and described the muscular mantle, phragmocone, uncinated arms, &c. of certain Cephalopods found in the Oxford Clay at Christian-Malford, and which he referred to a new genus under the name of *Belemnoteuthis*. According to the observations of this gentleman, and of subsequent authors, the body of this Cephalopod was of an elongated form, and contained a large internal conical shell, which is chambered and siphonated at its apical or distal extremity to the extent of about one-half (?) the length of the entire cone, and terminates anteriorly, or at its basal part, in a capacious chamber or cavity, in which the ink-bag, and probably other viscera, were placed. The external surface, which is of a brown colour, generally possesses a glossy smoothness, as if produced by its immediate contact with the secreting surface of the mantle. The outer integument of this conical shell consists of a thick corneo-calcareous layer (which for convenience I will call the epidermis), investing a nacreous, iridescent substance. Two large sessile eyes have been detected, and in several specimens the cephalic arms are more or less perfectly preserved; there are likewise indications of a pair of long tentacula, superadded to the eight shorter arms, as in the existing *Decapods**. The arms were furnished with acetabula or suckers, the horny hoops of which were beset with curved spines or hooks, as in the living *Onychoteuthis*. Traces of a pair of pallial fins have been detected by Professor Owen, to whose memoir I would refer for minute details of structure, which are not within the scope of the present communication†.

* Professor Owen, Philosophical Transactions, 1844, p. 78.

† Ibid. p. 79.

The outline, Plate XIV. fig. 1, is intended to convey an idea of the form of the animal of the *Belemnoteuthis*, so far as the fossils hitherto discovered warrant the restoration; of course this sketch is only approximative, and is given as a mere diagram of what is *actually known* as to the shape and structure of the original, and not as an accurate delineation of the living animal; for there are strong reasons to conclude that the phragmocone was wholly internal, or at least was covered by the skin. The above is, I believe, a correct description of the *Belemnoteuthis*, and of the form and relations of the several parts of its structure: it is based on the specimens described and figured by Mr. Channing Pearce, Professor Owen*, and Mr. Cunnington†, and others in my possession.

Now in order to connect the body of the Cephalopod above described with the elongated conical fossil commonly known as the *Belemnite*, and termed by naturalists the *guard* or *osselet* of the same, it has been assumed that the terminal chambered cone of the former (Plate XIII. figs. 2, 3, 5) was originally implanted in the alveolus or cavity of the latter; like the unquestionable phragmocone of a Belemnite, represented in Plate XV. figs. 4, 5, *a*, *a*. It follows, if we admit the correctness of this interpretation, that every example of the chambered conical shell of a Cephalopod, found in the Oxford Clay, is the phragmocone of a Belemnite that has slipped out of the alveolus of the guard, and been compressed into its present shape by the weight of the superincumbent strata. Upon the correctness of this supposition the generic identity of the *Belemnoteuthis* and the *Belemnite* entirely rests; for no specimen has yet been met with, in which the guard of a Belemnite is in *natural contact* with the muscular mantle, and other soft parts. If the phragmocone of the Belemnite, and the chambered shell of the Belemnoteuthis be not identical, then we know nothing whatever, *from actual observation*, of the soft parts of the animal to which the Belemnite belonged: to this point therefore I would first solicit particular attention.

Phragmocone of the Belemnoteuthis.—As the figures in the Philosophical Transactions, 1844, Plate III., &c., and in the London Geological Journal, Plate XV. XVI., show the phragmocone in natural connection with the muscular tunic or mantle, &c., I need not adduce further examples of this undisputed fact, and will therefore only remark, that such specimens are of rare occurrence: in most instances, the detached chambered shell, more or less flattened, is found imbedded in the clay, with but few, if any, vestiges of the soft parts, as in Plate XIII. figs. 1, 2, 3, 5. In this state, these fossils occurred by hundreds on the newly-exposed surface of the Oxford Clay near Trowbridge. My son describes some areas when first laid bare by his labourers, as being literally spangled over with the nacreous cones of Belemnoteuthes, and the splendid iridescent shells of Ammonites; while here and there Belemnites of large size, with their phragmocones attached, were lying in relief. Upon drying, the thin

* Philosophical Transactions, 1844, p. 77–80, Plates III. IV. V. VI.

† London Geological Journal, Plates XV. XVI.

nacreous shelly covering cracked to pieces, and flaked off from the clay: the illustrative examples presently to be described, were preserved by imbuing them with a thick solution of gum, and allowing them to dry, before attempting to dig them up. From a great number of specimens I have selected four (Plate XIII. figs. 1, 2, 3, 5.) in illustration of the form and structure of the phragmocone of the Belemnoteuthis. Figs. 2, and 3, exhibit, as I believe, the perfect shell, with the peristome, or mouth of the large anterior or basal chamber, entire. Although both these fossils are much compressed, the cavity of the receptacle filled with clay is distinctly seen in fig. 2: in fig. 3, the margin of the peristome (*a*) is only visible on one side, owing to the position of the shell in the clay. In both specimens the distal extremity is perfect; it terminates in a blunt point, having a longitudinal ridge on the side exposed, which probably indicates the dorsal aspect: in other instances, the corresponding space on the opposite or ventral side is occupied by two elevated, flat, slightly divergent longitudinal bands, as in Plate XIII. fig. 5; in fig. 2, the thick corneo-calcareous epidermis covers the lower part of the cone, but is in a great measure removed from the upper portion, and the pearly or nacreous layer of shell which lies beneath is exposed. The epidermis in fig. 3, though much cracked by pressure, extends over the greater part of the shell.

The descriptions of the phragmocone of the Belemnoteuthis, as given by Mr. Channing Pearce and Mr. Cunnington, accord in every respect with my own observations. Mr. Cunnington particularly dwells on the constant and uniform occurrence of the two strongly-marked ridges which extend upwards from the apex in a nearly parallel direction. "These," he observes, "are shown in Plate II. fig. 6. of Professor Owen's paper, and are regarded by that gentleman as resulting from the accidental crushing of the shell. I have, however, before me thirteen specimens, in which these ridges, though in some instances displaced by the compression they have undergone, are yet so distinct, and so constantly exhibit the same relative proportions and distances, that it is impossible not to regard them as resulting from original structure. A transverse section shows that these ridges are formed by an elongation of the fibres, and consequent thickening of the shell. Moreover, they are always exceedingly distinct in those specimens where the apex is solid—as is sometimes the case to the extent of half an inch—and has resisted the force that has compressed the rest of the shell. *It is obvious that this structure could never have fitted into the circular cavity constituting the alveolus of the Belemnite**." My son long since pointed out to me the marked difference in the form of the respective shells; that of the Belemnite being an elongated cone (Plate XV. figs. 4, 5, *b*), and that of the Belemnoteuthis more obtuse (Plate XIII. figs. 4, 5); and he remarked that no amount of pressure could reduce the former into the same angle as the latter.

[In the cabinet of the late Mr. Channing Pearce, there is a portion of a phragmocone of a Belemnoteuthis which is less compressed than any other specimen I have

* London Geological Journal, pp. 98, 99.

seen, and is also the only instance in which the true external surface of the epidermis is preserved. Through the kindness of Mr. Charlesworth I have been favoured by Mr. Pearce, Senior, with the loan of this fossil, which is represented in Plate XIII. fig. 1. The external pellicle, though cracked, is almost entire, but is removed in a few places (*a*, *a*, *a*), so as to expose the brown corneo-calcareous layer which in most specimens appears as the outer case, as in Plate XIII. figs. 2, 3. The surface is very finely striated with delicate interrupted elevated lines, disposed in a longitudinal direction, as shown in the slightly enlarged drawing of part of the same at fig. 1 *a*. This structure appears to be analogous to that observable on the back of the sepiostaire of the Cuttle-fish, and on the guards of certain species of Belemnites; but I have never observed any traces of such a texture on the surface of the phragmocones of the latter, which invariably presents the characters delineated in Plate XV. fig. 4, *a*.]*

According to the facts at present known, the chambered cone of the Belemnoteuthis appears to me to approximate most nearly to the *Belopteraf*, which has a horny calcareous conical shell with transverse septa, and is destitute of a guard.

The Belemnite.—To avoid unnecessary details, I beg to refer to Dr. Buckland's Bridgewater Essay‡, Professor Owen's Hunterian Lectures§, and my Medals of Creation‖, for descriptions and figures of the form and structure of the Belemnite as indicated by the specimens then known; and I now proceed to describe the most illustrative example from Trowbridge, which is represented (somewhat less than half the size of the original) in Plate XV. fig. 3. This fossil comprises the following parts:—

1. *The Capsule*¶ or *periostricum*; this external investment (*c'*, *c'*, *c'*), which consists of a thin shelly or corneo-calcareous integument that closely embraces the guard, and gradually enlarging upwards, finally surrounds the peristome of the phragmocone, constituting the thin horny laminated sheath or receptacle (*c*, *c*), has been described by all previous observers as an extension of what they termed the sheath or capsule; within this receptacle the ink-bag and other viscera were probably contained.

2. The *Guard* or *Osselet* (Plate XV. figs. 1, 2), which is the fossil known to collectors as the Belemnite. This is an elongated conical body, of a fibro-calcareous spathose structure, diminishing in size towards its distal extremity, and terminating in a point. At the basal, or opposite end, it is truncated, and has a deep conical cavity termed the *alveolus*, which contains the siphonated apical portion of the phragmocone.

3. *The Phragmocone* (Plate XV. figs. 3, 4, 5, *a*, *a*): this is a thin shelly inverted cone; the distal part containing a series of from twenty to thirty air-chambers or cells,

* *Received March* 16, 1848.—S. H. C.

† See Dr. Buckland's Bridgewater Essay, Plate 44', fig. 15.

‡ Ibid. Section VII. p. 371. § Vol. i. p. 333. ‖ Vol. ii. p. 462.

¶ I would restrict the term sheath, or *capsule*, to this outer corneo-calcareous case or integument, for the phragmocone cannot properly be said to have a capsule, its conical shell being inseparably connected with the transverse septa; it would be quite as correct to designate the involuted part of the shell of a Nautilus by this term, as the conical shell of the phragmocone of a Belemnite.

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formed by concavo-convex transverse septa or plates. This apparatus has been aptly compared by Dr. Buckland to a pile of watch-glasses, gradually diminishing in size towards the apex; the septa are perforated by a tube or siphunculus, which is situated on the ventral margin. The phragmocone enlarges upwards, and anteriorly to the siphonated part constitutes a large chamber, from the margin of which are produced two, or more, long, upright, shelly or calcareous processes, as shown in Plate XV. fig. 3, *b*, *b'*; these were probably for the support of the soft parts, or for the attachment of muscles. Whether there were similar processes on the opposite margin of the chamber cannot be determined, as the peristome is imperfect.

The figure in outline, Plate XIV. fig. 2, is intended to define these several parts more clearly.

a, *a*, *a*. The *Capsule, periostricum*, or external sheath of the Belemnite, now first described.

b. The *Guard* or *Osselet*.

c. The apical chambered part of the phragmocone which is situated in the *alveolus* or cavity of the *guard*.

d. The visceral or basal chamber of the phragmocone.

e, *e*. Two elongated processes produced from the margin of the peristome of the visceral chamber; observed for the first time.

In the specimens delineated, Plate XV. figs. 1 and 2, the guard is in great part covered by the external integument or shelly capsule (*c'*, *c'*, *c'*), which is very thin, and resembles in colour and in its glossy appearance, the outer coat or epidermis of the phragmocone of the Belemnoteuthis (Plate XIII. figs. 2, 3). The capsule is seen adherent to the crushed phragmocone beyond the upper part of the guard in Plate XV. fig. 2; and in fig. 3 it is shown to be continuous with the horny receptacle into which it ultimately expands (*c''*).

Professor Owen detected on the exterior surface of some spathose guards obtained from the Oxford Clay, "traces of a more immediate investment of a thin friable layer of white calcareous matter, analogous to that of the outer layer of the sheath of the phragmocone;" but the specimens were evidently too imperfect to demonstrate the nature of this *periostricum*, and its identity with the expanded capsule or horny receptacle above; for the phragmocone is erroneously described as having a sheath "continued backwards to line the alveolar cavity, and forwards from its basal outlet to form the visceral chamber anterior to the phragmocone*."

The appearance of the surface of the phragmocone situated in the alveolus, when first exposed by breaking away a portion of the investing guard, is represented, Plate XV. fig. 4, *a*; and the same specimen with part of the shell removed, to show the edges of the plates of the air-chambers, in fig. 5, *a*. The annular risings and depressions on the surface of the shell, fig. 4, *a*, indicate the situation of the concavo-convex transverse septa. The phragmocones of the Belemnites in the Oxford

* Philosophical Transactions, 1844, p. 69.

Clay of Wiltshire are not symmetrical; but the apex of the cone inclines to one side in consequence of the position of the axis of the guard, and terminates in a very fine point, as in the example, fig. 4. In this specimen the cells are filled with calcareous spar, as is frequently the case with that portion of the phragmocone which is implanted in the alveolus; a fact doubtless connected with the similar mineral state of the osselet itself. The latter is almost invariably saturated as it were with crystallized carbonate of lime of a brown colour and radiated structure; for notwithstanding the microscopical observations of Dr. Carpenter and Professor Owen, I think the evidence is in favour of the conclusion of the Dean of Westminster, that this crystalline condition has resulted from sparry infiltration, subsequently to interment, into the cellular and radiated calcareous texture of which the osselet was originally composed*; in like manner as the crustaceous coverings and spines of the Echinoderms in the Oolite and Chalk, are so saturated with calc-spar as to have acquired the hardness and peculiar oblique fracture of the crystalline mineral matter.

The facts above described appear to me to confirm the opinion advanced by Mr. C. Pearce and Mr. Cunnington, that the Belemnoteuthis is generically distinct from the Belemnite. In addition to the discrepancies in the form and structure of the phragmocones of the respective Cephalopods, pointed out by these observers, the specimen represented, Plate XV. fig. 3, demonstrates that in the Belemnite there are two other essential characters of which no traces have been detected in the Belemnoteuthis; namely, the periostricum, capsule, or external corneo-calcareous investment (c', c, c); and the processes that extend from the basal margin of the visceral chamber (b, b'), the peristome of the Belemnoteuthis being entire (Plate XIV. figs. 3, 4). It is worthy of remark, that the surface of the capsule of the Belemnite, and that of the phragmocone of the Belemnoteuthis, are alike smooth and glossy; as if in the one the osselet, &c., and in the other the chambered shell, were originally wholly enveloped by the mantle. But the exterior of the siphonated phragmocone of the Belemnite is devoid of polish, and is in such close contact with the walls of the alveolus, that it is very rarely the shell can be displayed entire as in the specimen, Plate XV. fig. 4.

If it be contended that upon physiological grounds the phragmocone of the Belemnoteuthis must have been implanted in the alveolus of a guard or osselet, I would reply that none of the species of Belemnites with which these chambered cones are associated in the Oxford Clay of Wiltshire, can have belonged to them, for the reasons already assigned; and a guard has still to be discovered that shall meet the exigencies of the case. If, therefore, with our present scanty information, we affirm that the Belemnite and the Belemnoteuthis belong to one and the same genus, I respectfully submit that we are not only reasoning in advance of the data hitherto obtained, but contrary to known facts.

From a tolerably extensive knowledge of the fossil Cephalopoda of the argillaceous strata of the Oolite and Lias, I am led to conclude that the Oxford Clay of Wiltshire

* Bridgewater Essay, p. 372.

contains the remains of at least three genera of naked Cephalopods; namely, the Belemnite, Belemnoteuthis, and a true Calamary with a horny dorsal gladius or pen. In the two last, vestiges of an ink-bag, or of its inspissated contents, are generally manifest; but I have never detected the slightest trace of the existence of such an organ in natural connection with any part of a Belemnite; and I learn from M. Van Breda, that in the very large collection of Belemnites of the late Count Munster, there was not one unequivocal instance of this kind. If in the specimens figured in the Bridgewater Essay, Plate 44', fig. 7, the ink-bag be in its natural position, and not merely in accidental apposition with the basal chamber of the phragmocone of a Belemnite, of course the question as to whether this genus of Cephalopods was furnished with such an organ, is decided in the affirmative.

In conclusion, I would state, that although I am of opinion that the body and soft parts, and consequently the true characters of the animal of the Belemnite, have yet to be discovered, I do not question the soundness of the views of the correlation of cephalopodal organization, and of the physiological inductions resulting therefrom, enunciated in the memoir on the Belemnite by the Hunterian Professor. That the unknown animal of the Belemnite closely approached the Belemnoteuthis, both in form and structure, is highly probable, but proofs are yet required to confirm the inferences of the physiologist.

19 *Chester Square, Pimlico,*
February 1848.

Description of the Plates.

All the figures are from specimens in my possession, and of the natural size, with the exception of fig. 3, Plate XV., which is much reduced, the original specimen being twenty-two inches long.

PLATE XIII.

Figs. II. III. V. Phragmocones of *Belemnoteuthis antiquus*.

a. The basal or upper or anterior part, forming a chamber for the ink-bag, and probably other viscera.

b. The apical or distal termination of the shell.

Fig. I. The apical portion of the phragmocone of a Belemnoteuthis invested with the external integument; at *a*, *a*, *a*, is seen the corneo-calcareous layer which lies beneath.

Fig. I*. Part of fig. 1, slightly magnified to show the striated surface; *a*. marks a denuded space, exposing the internal layer.

Fig. II. Shows the perfect form of the peristome, *a*; though much compressed, the cavity of the chamber, partially filled with clay, is well-defined.

Fig. III. This specimen is also perfect, but in consequence of its position in the clay, only one-half of the basal or upper part of the margin of the peristome (*a*) is visible.

Fig. IV. *Ammonites Jasoni*, from Trowbridge, with two elongated processes extending from the margin of the aperture, bearing some analogy to the shelly prolongations from the peristome of the Belemnite, Plate XV. fig. 3, *b*, *b'*.

Fig. V. A phragmocone showing the ventral (?) aspect of the chambered apex, with two parallel longitudinal bands extending upwards (*b*).

PLATE XIV.

Fig. I. A restored outline of the animal of the Belemnoteuthis, so far as at present known.

a. The cephalic arms.
b. Remains of a pair of long tentacula.
c. The eyes.
d. The pallial fins.
e. Ink-bag.
f, *f*. The mantle.
g. The phragmocone; the letter indicates the visceral chamber of the same.
i. Apical or distal part of the phragmocone.
k. Two longitudinal bands on the ventral aspect of the same.

Fig. II. Outline of the known parts of the Belemnite.

a, *a*. The capsule or *periostricum*.
a', *a'*. The horny expansion of the same forming the receptacle which surrounds the basal chamber and peristome of the phragmocone.
b. The guard or osselet, one-half being removed to show the radiated structure, and the alveolus with the apical part of the phragmocone, at *c*.
c. The chambered distal extremity of the phragmocone.
d. The visceral chamber of the same.
e, *e*. Two calcareous processes arising from the margin of the peristome at *f*, *f*.

Fig. III. Phragmocone of Belemnoteuthis.

a. The visceral chamber.
b. Ridge on the dorsal side of the apex.

Fig. IV. A phragmocone of Belemnoteuthis seen on the ventral aspect.

b. Two nearly parallel elevated longitudinal bands.

PLATE XV.

Fig. I. The guard or osselet of a Belemnite (*B. attenuatus*) invested by the *periostricum*, or external shelly capsule, c^{I}, c^{I}, c^{I}.

a. Part of the chambered phragmocone seen in the alveolus.

Fig. II. Another example of *B. attenuatus*, on which a large portion of the capsule remains, c^{I}, c^{I}.

Fig. III. Exhibits the most considerable part of the structure of the Belemnite hitherto discovered. The original is twenty-two inches in length.

a, *a*. Remains of the basal portion of the shelly phragmocone; the apical chambered extremity is concealed by the investing capsule and guard, *c*, *c*.

b, *b*. Two shelly processes proceeding from the margin of the peristome.

c, c^{I}, c^{II}. The capsule partially investing the guard (at c^{I}), and extending upwards conceals at *c*, *c*, *c*, the siphonated part of the phragmocone, and expands into the horny receptacle (c^{II}), within which the peristomal processes (*b*, b^{I}) are contained.

A layer of dark brown animal matter extends from within the outline of the capsule at c^{II}, under the processes of the peristome; and is probably the remains of the soft parts that occupied the interval between the receptacle and the phragmocone. The band on the left of the process *b*, presents a fibrous structure (*d*, *d*), and is marked with oblique lines, as if it were part of the muscular tunic or mantle.

Fig. IV. The alveolar part of the guard of a Belemnite split open longitudinally to show the apical chambered portion of the phragmocone (*a*), with the shell perfect, and imbedded in the alveolus. The phragmocone terminates in a very fine point, and is unsymmetrical; inclining considerably to one side, in consequence of the position of the axis of the guard (*c*). A comparison of this figure with figs. 2, 3, 5, Plate XIII., will at once enable the observer to perceive how essentially the phragmocone of the Belemnite differs from that of the Belemnoteuthis.

b. The radiated fractured surface of the spathose substance of the guard.

Fig. V. The same fossil, with the phragmocone partially divested of the outer shell, to display the edges of the transverse septa. I have never seen in the Oxford Clay, the apical part of the phragmocone of a Belemnite detached from the alveolus.

XIII. *On the Structure of the Jaws and Teeth of the Iguanodon.*

By Gideon Algernon Mantell, *Esq.*, *LL.D.*,
F.R.S., *F.L.S.*, *Vice-President of the Geological Society*, *&c.*

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In the deltas and estuaries of rivers that are of great extent, and which flow through countries of varied geological structure, we naturally expect to find the remains of terrestrial vertebrated animals that have been transported by the currents from far-distant lands, in a more or less mutilated state; the skeletons broken up—the bones dissevered, fractured, and waterworn—the teeth detached from the jaws and dispersed—and all these separated parts promiscuously imbedded in the mud, silt, and sand of the delta, and intermingled with the debris of the flora of the country, and the durable remains of fishes, mollusks, and crustaceans, that inhabited the freshwater, or were denizens of the adjacent sea. Such is the condition in which the bones and teeth of oviparous quadrupeds are found in the Wealden formation of the south-east of England; and hence the difficulty of obtaining satisfactory evidence of the form and structure of the extinct reptiles whose relics are so abundant in some of these deposits.

To this cause may be ascribed the remarkable fact, that although several hundred teeth, belonging to seven or eight genera of Saurians, have been collected from these fluviatile strata, scarcely a portion of the cranium, and but a few fragments of the jaws, have been discovered. Every relic of this kind is consequently in the highest degree interesting, and it is therefore most gratifying to me to have it in my power to lay before the Royal Society a considerable portion of the lower jaw, with teeth, of an Iguanodon, recently obtained from a quarry near Cuckfield in Sussex; the locality in which, nearly thirty years since, I first discovered the teeth of this colossal herbivorous Lizard.

In the communication which I had the honour to address to this Society in 1841*, a fragment of the lower jaw of a Saurian was described as that of a young Iguanodon, and the anatomical considerations which led me to offer that interpretation were fully detailed. But although from the form and mode of implantation of the fangs of the mature teeth, and the position of the germs of the successional ones, this inference appeared to be highly probable, yet as none of the crowns of the teeth remained, the peculiar dental characters of the Iguanodon were absent, and the presumed generic identity could not be unequivocally established; since it was possible

* Philosophical Transactions, Part II. p. 131.

that the fossil might belong to the Hylæosaurus, or to some other genus of reptiles whose bones occur in the Wealden deposits.

The specimen to which I now solicit attention consists of nearly the entire dentary and coronoid bones of the right side of the lower jaw of an adult animal, retaining two successional teeth in place, and the germ of a third, with the alveoli or sockets of seventeen or eighteen mature molars. This fossil is the first indisputable portion of a jaw of the Iguanodon hitherto brought to light; although nearly a quarter of a century has elapsed since the publication in the Philosophical Transactions* of my first memoir on the teeth of this extinct reptile.

From the striking analogy presented by the worn teeth of the Iguanodon to the condition of the abraded molars in some of the large herbivorous Mammalia, the discovery of the maxillary organs of this reptile was an object of the highest palæontological interest, in order to determine in what manner the mastication of vegetables was effected by an animal belonging to a class, in which no living species is provided with jaws so constructed as to be capable of a triturating or grinding motion; nor with cheeks to retain the food while such a process is performed†. And though from the absence of mature teeth in the sockets, and of the articular portion of the jaw, the proximal end being destroyed, the specimen before us does not afford a complete solution of the problem, yet it possesses characters sufficiently definite and intelligible to throw important light on the structure and functions of the dental organs of the Iguanodon; and it has also enabled me to ascertain the form of the upper jaw, from a portion of the left maxillary bone, collected many years since, and now in the British Museum, but whose peculiar characters I was previously unable satisfactorily to interpret.

Before entering upon the description of the highly interesting fossil which forms the principal subject of this memoir, I beg to express my most grateful acknowledgments to Captain Lambart Brickenden, of Warminglid, Sussex, by whom it was discovered, and skilfully extricated from the sandstone in which it was imbedded; and who, although I was personally unknown to him, in the true spirit of an ardent and liberal promoter of science, placed it at my disposal, as the original investigator of the fossil Saurians of the Wealden; a tribute of respect that I regard as a high reward for my humble efforts to advance those branches of natural knowledge, to which I have devoted the leisure moments of a life of professional toil.

The specimen when discovered was imbedded in a block of the fawn-coloured sandstone which occurs interstratified with beds of clay and limestone, throughout a considerable part of the Wealden districts of the south-east of England; fortunately this stone is not very compact, so that organic remains can be extricated from it by a skilful manipulator, with but little difficulty. This fossil, like most of the bones and teeth

* "Notice on the Iguanodon, a newly discovered Fossil Reptile, from the Sandstone of Tilgate Forest, in Sussex."—Philosophical Transactions for 1825.

† See Cuvier, Oss. Foss. tome v. p. 351.

found in the sandstone, is heavy, and of a rich umber colour, from impregnation with oxides of iron. It consists of the dentary, and part of the coronoid or complementary bone, of the right side, and is entire at the anterior part, but the posterior or opposite extremity is imperfect, probably to the extent of several inches. Its original relative position in the jaw will be understood by referring to my former communication*, in which the peculiar construction of the lower jaw in Saurian reptiles is described. In this place it may, however, be proper to remark, that of the six pieces on each side of which the inferior maxilla consists, that containing the teeth, and forming the anterior portion or symphysis, is termed the *dentary*; and the posterior part of this bone is united on the outside by suture to the *complementary* or *coronoid*, *angular*, and *surangular*; while on the mesial or inner side, it is covered below and behind the teeth by an expansion of the *opercular* bone.

The specimen is represented of the natural size in Plate XVI.; its dimensions are as follow:—

	inches.
Length from the front of the symphysis to the posterior extremity of the bone	21
Greatest width of the outer surface measured over the convexity, from the lower margin to the upper alveolar edge	6¾
Greatest thickness at the posterior part	2¾
Length of the alveolar parapet for twenty teeth	15
Breadth from the anterior termination of the alveolar space across to the inner margin	4¼
Height of the alveolar parapet at the posterior part	2
Width of the alveolar space at the posterior part	1½
Width of the alveolar space at the anterior part	¾
Length from the first anterior tooth to the symphysial extremity	5

Height of the successional tooth (Plate XVI. fig. 1, *b*) 1½ inch; greatest width ¾.

The mesial or inner aspect of the fossil (Plate XVI. fig. 1) is flattened and smooth, and shows the successional teeth which remain in their original places (*a*, *b*), and the sockets (*f*, *f*, *f*,) for nineteen or twenty teeth; the inner alveolar plate having been destroyed, and the mature molars dislodged, before the bone was imbedded in the rock. The deep conical groove or furrow, so constantly present on the inner side of the dentary bone in reptiles, and which from its being covered by the splenial or opercular piece, it may be convenient to designate the *opercular furrow*, is here entirely exposed (fig. 1, *d*, *d*) in consequence of the removal and destruction of that maxillary element. It is very large, and prolonged anteriorly (*d*) to within six inches of the symphysis; the opercular piece must therefore have more nearly corresponded with that of the Varanians or Monitors than with the Iguanas, in which it is of a rhomboidal figure, and relatively of limited extent. The lower margin of the jaw is thick and convex at the posterior part, and gradually becomes thinner towards the front, where it expands horizontally into a broad scoop-like process, which is terminated anteriorly by an obtuse projection or tubercle (Plate XVI. fig. 1, *e*); it thins out mesially to form the symphysial suture (*s*) that connects it with the opposite ramus.

The upper margin is formed by the alveolar process, which has a thick external

* See Philosophical Transactions for 1841, Plate V. figs. 3. 7.

parapet, deeply furrowed on the inner side, as seen in this view, by the sockets for the mature teeth (*f*, *f*). Strongly-defined ridges occupy the interspaces, and rising above the sockets produce a sharp crenated upper border. The alveolar space is protected on the inner side by a moderately strong plate or wall, which must originally have nearly equalled the outer parapet in height, but is now in a great measure broken away: within this process the germs of the successional teeth were developed.

The mode of implantation of the teeth appears to have been intermediate between the pleurodont and thecodont types; for the teeth were not anchylosed to the alveolar wall as in the Iguanas, but free as in the Crocodiles; yet as the ridges that separate the dental sockets are smooth and rounded, it may be inferred that these were not rendered complete alveoli by transverse plates extending from the outer to the inner parapet, as is the case in the Megalosaurus*.

The dental sockets diminish in size, but somewhat irregularly, from the posterior to the anterior termination of the alveolar process; and the latter suffers a corresponding diminution in breadth, and terminates suddenly at the distance of five inches from the front. At this point the upper margin becomes attenuated and contracted in a vertical direction, and descending with a gentle curve, expands horizontally and mesially to unite at the symphysial suture (*s*) with the opposite ramus, the anterior part of the jaw being edentulous.

From the fortunate preservation of two successional teeth in their original position, the mode of dental development in the Iguanodon is clearly demonstrated. The coronal portion of the tooth was first formed, as seen in the germ, Plate XVI. fig. 1, *a*; and the entire crown was completed (fig. 1, *b*) before the secretion of the shank or fang commenced, as in the existing Saurians. The formative pulp was situated in a distinct depression or cavity, on the inner side of the root of the tooth it was destined to supplant: this is obvious by the positions of the teeth above described; and also by the remains of a third germ towards the posterior part (fig. 1, *c*).

Although the peculiar characters of the molars of the Iguanodon were described somewhat in detail in my former communications, and the present fossil confirms in every essential particular the inferences suggested by the detached teeth, as stated in my memoir of 1825, yet several new and important points relating to the development and functions of the dental organs, are elucidated by the new acquisition which Capt. Brickenden's researches have brought to light. The second tooth (Plate XVI. fig. 1, *b*) which occupies its natural position in the alveolar space, consists of the entire crown, having the serrated margin as perfect as in the recent state; and this is the first evidence I have obtained as to the mode in which the teeth were implanted. The flat enamelled front, characterized by its longitudinal ridges, is placed mesially, and parallel to, and within the inner alveolar wall; the smooth convex face filling up a depression in the outer parapet, in the interspace of two sockets of the mature molars. This position is the reverse of that in which the successional teeth in the Iguana are developed; for in that reptile the coronal germ occupies the same relative place as

* See Dr. Buckland's Bridgewater Essay, Plate 23.

in the mature state; namely, with the ridged face outwards, and the smooth side inwards, or towards the cavity of the mouth.

As the coronal portion of the tooth in the Iguanodon is not symmetrical, one lateral margin presenting a gentle curvature (Plate XVIII. fig. 4, *a*), and the other forming a broad angle at the base of the serrated border (Plate XVIII. fig. 4, *b*), the teeth belonging to one side of the lower jaw may readily be distinguished from those of the other; the lateral marginal angle (*b*) being always situated posteriorly. Guided by this character, Dr. Melville and myself examined the numerous teeth in the British Museum and in my own collection, and were enabled readily to determine to which ramus any tooth belonged. Thus, for example, the specimen represented, Plate XVIII. fig. 4, which is the very counterpart of that implanted in the jaw (Plate XVI. fig. 1, *b*), is a perfect successional tooth, consisting of the crown before the formation of the fang, and belonging to the right side (*a* denotes the anterior, and *b* the posterior angle). The specimen, Plate XVIII. fig. 5, appertained to the opposite or left lower side, as is shown by the situation of the posterior marginal angle (*b*).

The position of the lower teeth in relation to the alveolar process, appears to have been somewhat changed during the upward growth of the coronal portion consequent on the progressive development of the fang; and it seems probable that the face of the crown became inclined rather obliquely forwards and outwards, and that the mature teeth were arranged in an imbricated manner. This opinion is supported by the form of the alveoli in the outer parapet, and the corresponding oblique curvature in the fangs of the mature molars, as shown in Plate XVIII. fig. 5; but this inference does not admit of that absolute proof which the perfect adaptation of a full-grown tooth to one of the sockets would afford; for the alveoli are irregular, and none of the detached teeth in my possession will fit either of the sockets in the recently discovered dentary bone.

The situation of the germ in relation to the tooth it was destined to supplant, is invariably on the inside of the mouth; in the lower molars the excavation in the mature tooth occasioned by the upward growth of the germ, is consequently on the enamelled mesial face, as is shown in my original memoir*: in the upper tooth the germ was lodged in an excavation on the smooth convex aspect, as will subsequently be demonstrated (see Plate XVIII. fig. 2^a, *f*).

In the fossil represented in the annexed sketch, the cavity produced by the pressure of the germ is situated in the fang of the tooth in place; in other examples, however, the successional dental excavation is on the base of the enamelled crown; for in the Iguanodon the old teeth were retained till nearly the entire coronal portion was worn away, and the crown of the tooth, from the abrasion by use above, and the removal of the fang by absorption below, was reduced to a mere disk, before it was finally shed; as in the specimen (figured in Xylograph, No. 2, p. 188).

Xylograph, No. 1.

Lower tooth of the right side.

* Philosophical Transactions, 1825, Plate XIV. fig. 7 *a*.

As the surface of the crown when abraded by mastication invariably possesses two distinct facets (Xylograph, No. 4, and Plate XVIII. figs. 1^b and 2^b), it is obvious that the arrangement of the lower teeth in relation to the upper was intermediate, or subalternate, as is the case in the ruminants; the further consideration of the dental characters of the Iguanodon will be resumed in a subsequent part of this memoir.

Xylograph, No. 2.

Lower tooth reduced by abrasion of the crown and absorption of the shank.

Cavity formed by the pressure of a new tooth.

Enamelled face.

Coronal surface worn flat by use; showing a radiated structure.

The *external aspect* of the specimen (Plate XVI. fig. 2, and Plate XVII. fig. 4) presents in its transverse diameter a gentle convexity, traversed by a slightly elevated longitudinal ridge, which lies parallel to, and immediately beneath, the row of vascular foramina, commonly met with in this part of the lower jaw in reptiles; and towards the posterior extremity the side of the bone is somewhat compressed below the longitudinal eminence; according in this respect with the portion of a lower jaw of a much smaller reptile, described in a previous memoir*. The upper edge of the bone is formed by the outer alveolar parapet, which is deeply scalloped or crenated by the terminations of the sockets of the teeth; the angular eminences indicate the intra-alveolar ridges. A reference to the figures (Plates XVI. and XVII.) will impart a more correct idea of the configuration of this part of the fossil than any verbal description. The whole surface of the bone is covered with minute punctuations and striæ.

The relative thickness and proportions of the different parts of the specimen, and its external contour, are shown in the reduced figure of the section exposed by the fractured posterior extremity, Plate XVII. fig. 3; and in this view is seen the dental canal (*s*) which contained the large blood-vessels and nerves that supplied the teeth and integuments of the lower jaw; its longest diameter at this part is six-tenths of an inch.

The numerous and large vascular foramina which afforded passage to the vessels and nerves from the dental canal to the external integuments, form a striking character in this aspect: they open obliquely forwards; nine are distributed at regular intervals in a line with the alveolar margin, from the posterior end of the bone to nearly opposite the successional tooth in place. A fracture in the middle of the outer surface (Plate XVII. fig. 4, *h*) at the distance of $4\frac{1}{2}$ inches from the posterior end, exposes the dental canal filled with sandstone: its diameter is here two-fifths of an inch.

At the anterior termination of the alveolar space, a slight protuberance (Plate XVII. fig. 4, *i*) marks the commencement of the upper margin of the symphysial region, which is defined by a sharp smooth ridge, that sweeps downwards and inwards to form the front of the jaw. A deep groove, beset with foramina (Plate XVII. fig. 4, *k*),

* Philosophical Transactions, 1841, Plate V. figs. 1, 8, 9.

constitutes a strong line of demarcation between the inner and outer boundary of this area; the latter is thick and convex, and terminates anteriorly, as already mentioned, in a mammillary protuberance or tubercle (Plate XVI. *e*, and Plate XVII. fig. 4, *e*). A series of foramina, eight in number, extends along the outer and inferior surface of the symphysis; the terminal one, which is three-fourths of an inch in its transverse diameter, is situated immediately under the mental tubercle (*e*) above described. The mesial or inner edge of the symphysis, which in connection with the ramus of the left side formed the median suture of the lower jaw, is thin and expanded; the articulating surfaces of the two dentary bones appearing to have overlapped each other (Plate XVI. fig. 1, *s*, and Plate XVII. fig. 1, *s*, *s*); but as the edge of the bone is somewhat broken, the line of junction is not quite determinable; but the two rami do not seem to have been united by anchylosis.

On the under surface of the symphysis there is a depressed oval area, bounded laterally and posteriorly by a slightly elevated ridge (Plate XVII. fig. 2, *l*, *l*); probably for the insertion of the protractor muscles of the tongue.

The coronoid bone (Plate XVI. fig. 1, *m*, and Plate XVII. fig. 4, *m*), of which only a portion remains, is much more expanded outwardly than in any recent Saurian.

With respect to the length of the jaw to which this specimen belonged, an approximative estimate only can be offered, since we have no means at present of determining the relative size of all the different pieces that entered into the construction of the maxillary organs of the Iguanodon. From the appearance of the fractured end, it seems probable that the dentary bone was prolonged backwards five or six inches before it united with the surangular and angular: upon this supposition its entire length must have been two feet, and the number of teeth about twenty. In the Iguana and most Lizards the dentary element is half the length of the jaw; and if this proportion be taken as the standard of comparison—and it appears to be the most probable one—the length of the jaw of this individual was four feet. An eminent palæontologist* has estimated the length of the head of the largest Iguanodon at only thirty inches; having taken as the basis of his calculation, the length of six dorsal vertebræ, which in the Iguana is equal to that of the lower jaw. But the specimen before us proves either that the same scale of proportions is not applicable to this colossal Saurian, or that much larger dorsal vertebræ than those from which the measurement was taken, are yet to be discovered; for several teeth in my possession exceed in magnitude the largest sockets of this dentary bone. Even if we take the

* Reports of the British Association for 1841. Article 'British Fossil Reptiles,' p. 143. "If there be any part of the skeleton of the Iguana which may with greater probability than the rest be supposed to have the proportions of the corresponding part of the Iguanodon, it is the lower jaw, by virtue of the analogy of the teeth and the substances they are adapted to prepare for digestion. Now the lower jaw gives the length of the head in the Iguana, and this equals the length of six dorsal vertebræ; so that as five inches rather exceeds the length of the largest Iguanodon vertebra yet obtained, with the intervertebral space superadded, on this calculation *the length of the head of the largest Iguanodon must have been two feet six inches.*"

abbreviated proportions of the short blunt-headed lizards as the scale—as for example the Chameleons—the length of the jaw of this Iguanodon must have exceeded three feet.

I will now describe the portion of a left upper maxilla in the British Museum, which corresponds so perfectly in its general characters with the lower jaw, as to leave not the slightest doubt of its having belonged to the Iguanodon, although no teeth remain to establish the identity.

Portion of the Upper Jaw, Plate XIX. figs. 1, 2*.—This specimen consists of the anterior part of the left maxillary bone, having on the under surface (fig. 1) the alveolar furrow with the bases of the sockets of ten teeth; and on the upper (fig. 2), the deep channels of the infra-orbital vessels and nerves that supplied the teeth and integuments of the front of the jaw and face on the left side: this fossil is represented of the natural size. Dr. Melville, who has most kindly aided me by his profound anatomical knowledge throughout this investigation, and liberally devoted much time and attention in instituting the necessary comparisons between my specimens and those formerly collected by me, and now in the British Museum, with the jaws and teeth of recent reptiles, has favoured me with the following observations on this subject.

"This fragment of the left maxilla, which is eight inches five lines long, and two inches seven lines broad, formed the lower boundary of the nasal surface; it is broken off where the vertical parapet rises to enclose the olfactory fossa. The corresponding part in the skull of an Iguana (*I. tuberculata*), measuring four inches two lines in length, is six lines long, or nearly one-eighth that of the cranium; this ratio gives five feet four inches as the length of the skull of the Iguanodon to which the fossil belonged; but as the brain and the organs of sense would have a less proportion to the whole bulk in these gigantic Saurians than in the small species of existing Lizards, we may infer a diminution in the absolute size of the head, corresponding with the abbreviation and contraction of the cranium; and the length in the adult would probably average about four feet.

"The breadth of the fragment continues uniform; in front it is rounded off externally (*x*), and exhibits the oblong terminal irregular surface for articulation with the intermaxillary bone by which it was overlapt. The large infra-orbital canal (fig. 2, *a*, *a*) opens at the junction of the posterior and middle third, and midway between its margins; passing into a broad and deep sigmoid groove which curves inwards as it advances so as nearly to reach the inner edge in the centre of its course, where it gives off a retrograde furrow extending over the internal margin (fig. 2, *b*). In front it is deflected outwards, extending along the posterior border of the intermaxillary

* I discovered this fossil in 1838, in a quarry near Cuckfield, and it was labelled in my Catalogue "*fragment of the upper jaw of an Iguanodon.*" By the kind permission of Mr. König, the specimen has recently been cleared of the sandstone with which it was partially invested, so as to expose its peculiar characters as represented in Plate XIX.

surface; and rising to a higher level, becomes faint, and terminates one inch behind the anterior extremity; several small vascular foramina open where it ceases. A rough, irregularly triangular, and excavated tract, separates it from the outer edge of the bone; its apex is behind, about 1½ inch from the infra-orbital orifice; its base corresponds to the rounded anterior and external angle, where it passes into the low external border.

"The roof of the infra-orbital canal presents a deep concavity behind (fig. 2, *c*), with the smooth lateral surface of the groove rising into it externally; this is evidently part of the floor of an upwardly emergent canal about an inch in diameter; the thin partition continued backwards between it and the canal below is destroyed, and the posterior segment of the circumference removed; a comparison of the fossil with the skull of an Iguana will confirm this statement.

"The infra-orbital canal, which is eight lines wide behind and four lines high, bends inwards as it retrogrades from its anterior opening. The inner surface is only four lines from the nasal aspect of the fragment behind, so that after a course of a few inches, it would have emerged on the floor of the nasal cavity. The roof is incised obliquely outwards, and the inner portion of it extends forwards to the retrograde groove. The portion of the external surface of the alveolar process that remains, slopes inwards, and exhibits no traces of vascular foramina."

From the almost entire destruction of the alveolar walls of the furrow, deep transverse excavations (Plate XIX. fig. 1, *f*, *f*, *f*) are the only remains of the dental sockets. As the fangs of the teeth of the upper jaw, as will be shown in the sequel, were more curved than in the lower series, and their implantation presented a corresponding modification, as is the case in the dental organs of certain existing Monitors, the width of the alveolar space is greater than in the lower jaw.

Dental characters.—Although the peculiar form and structure by which the teeth of the Iguanodon are distinguished from those of all other animals have been described in my former communications, yet as the mode in which the teeth were implanted in the jaws was then unknown from actual observation, no attempt was made to ascertain the dextral or sinistral position of the detached specimens; nor to separate the lower from the upper series, and thus determine the dental arrangement by which the jaws of this colossal reptile were invested with the functions of those of the existing herbivorous Mammalia. To solve this highly interesting problem, it became necessary to institute a rigorous and minute comparison and examination of all the teeth of the Iguanodon to which we could obtain access; the results of the investigation are detailed by Dr. Melville in the following statement.

"*Teeth of the Lower Jaw*, Plate XVIII. figs. 4, 5, 6.—The lower tooth is curved, with the concavity outwards, or towards the external alveolar parapet; the upper and lower limbs, corresponding respectively to the wedge-shaped crown, and elongated taper fang, are not separated by a constriction or neck, but are flattened in opposite directions. In the upper moiety of the coronal segment, it is compressed

transversely with a convex outer, and a flat inner aspect, and gradually increases downwards in width and thickness, from the broadly-rounded excentric apex to its greatest longitudinal diameter. It continues to expand transversely while decreasing in breadth; subconcave planes also replace the serrated edges at which the surfaces meet above; it obtains its greatest thickness where the tooth is bent on itself to form the fang; the latter diminishes rapidly in both diameters, and the lateral facets are brought in contact below, and obliterate the inner surface; in fully-formed teeth the fang tapers to a point*.

"The inner coronal aspect has a rhomboidal outline, and is covered with a thin layer of enamel extending on the margins; it is flat in the antero-posterior diameter, and only slightly convex vertically. The upper serrated edges ascend converging; the anterior is the longest and most curved; it sweeps rapidly backwards above to the excentric apex, which thus presents a broad front shoulder. The inferior margins are striated or granulated, but destitute of serrations; the posterior is bent forward below to meet the straight lower front edge. The angle to which the hinder margin inclines is more prominent and acute than that formed by the anterior edge; and by this character the teeth belonging to the respective rami of the lower jaw may be distinguished.

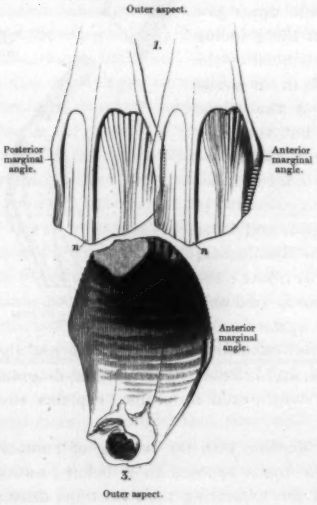
"The enamelled surface is divided into two unequal channelled areas by a primary longitudinal ridge (Plate XVIII. fig. 4, *n*, and fig. 5, *n*); commencing at the apex, it intersects the long diagonal, and terminates behind the lower angle, from which a broad secondary elevated tract ascends along the floor of the wide anterior groove, nearly obliterating it in front. A slight convexity, rapidly subsiding, passes upwards in front of the superior posterior edge.

"The relative width and depth of the longitudinal grooves, and the prominence of the intervening ridges, vary in different specimens; and the edges of the ridges are more or less replaced by planes; the ratio of the upper to the lower margins also differs. The serrations are produced by small convex mammillated ridges separated by slight intervals; the inner edges of the anterior apical ones are prolonged downwards; those on the posterior margin are abraded, apparently by absorption, during the upward growth of the germ. The inner convex surface of the fang is variously grooved and flattened, becoming ridge-like below; it is in apposition with the outer alveolar parapet. The lateral planes converge inwards, and are grooved longitudinally: the posterior plane presses forwards the inferior hinder coronal margin; they extend as high as the obtuse angle of the crown, and leave between them, as they diverge in their ascent, an unenamelled triangular space on the inner aspect. Expansions of the alveolar septa on each side are adapted to the lateral planes of the fang, and the inner parapet is deficient opposite the triangular tract above-mentioned, but is closed below, separating the alveolus from the cavity of reserve in the secondary dental groove.

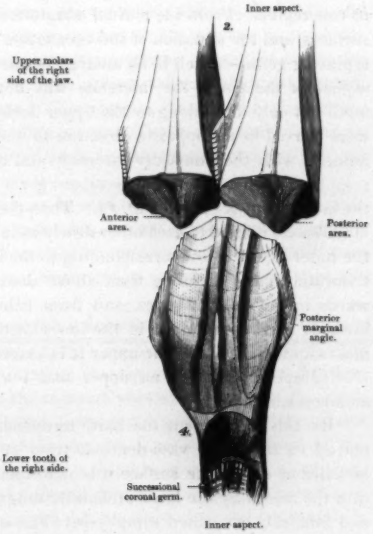
* Philosophical Transactions, 1841, Plate VII. figs. 1, 2.

"The teeth never become anchylosed to the sockets; the great transverse diameter of the dentary element of the jaw above appears to have allowed of the outward curvature of the elongating fang, while the inner surface was maintained nearly vertical. By the same provision the germ attained a considerable size before it pressed upon and excavated the root of the tooth, which it was destined ultimately to displace. The wedge-shaped crown and the anterior serrated recurved trenchant edge, must have rendered the teeth in this early stage very efficient instruments, in the absence of incisors, for cutting vegetable food.

Xylograph, No. 3.



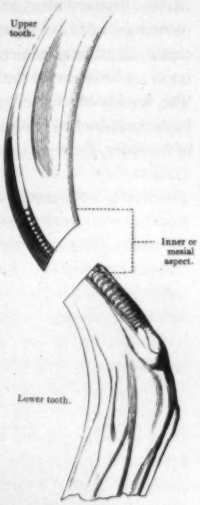
Xylograph, No. 4.



The arrangement of the upper and lower molars, and the situation of a lower successional germ, are shown in the above figures. In the wood-cut No. 3, two upper molars of the right side are represented on their external or enamelled aspect, and a corresponding lower molar beneath them; in No. 4, are seen the opposite or internal aspect, and the position of the successional germ in the fang of the lower tooth.

"*Teeth of the Upper Jaw*, Plate XVIII. figs. 1, 2.—After the determination of the form and position of the teeth of the lower jaw, yielded by the instructive specimen previously described, the next question to be determined was, whether the teeth in the upper maxilla had the same shape and curvature as those of the lower. Upon examining the extensive series in the British Museum, several teeth were found differing in shape from the now-ascertained type of the lower molars of the Iguanodon. These are, however, in all essential respects so analogous to the inferior teeth, that no reasonable doubt can exist of their having belonged to the upper jaw of this reptile. From the mutual adaptation of the grinding surfaces, and the situation of the excavation produced by the replacing germ—which in all analogous cases is in the mesial aspect of the fang—the inference was obvious that these teeth not only did belong to the upper series, but that they were curved in an opposite direction to those of the lower; namely, with the convexity external, and the concavity internal; the hollow for the successional germ being situated in the latter (Plate XVIII. fig. 3*, *f*). Thus the upper and lower molars were related to each other nearly as in the Ruminants; the outer aspect below corresponding to the inner above; the triturating facet inclining from above downwards and outwards in the inferior series, and from below upwards and inwards in the superior; in the lower teeth the enamelled edge is within and the most elevated, while in the upper it is external and inferior. The annexed diagram (Xylograph, No. 5) of an upper and lower tooth, seen in profile, explains this arrangement.

Xylograph, No. 5.



View in profile of an upper and lower molar, of the left side.

"By this adjustment the hard unvascular dentine with its coating of enamel, played on the softer vaso-dentinal tract of the tooth opposed to it below; and a bevelled or chisel-like surface was maintained for triturating the food when drawn into the mouth by the large prehensile tongue, which is indicated by the procumbent and inferiorly excavated symphysis. The upper molar is also distinguished by the smaller antero-posterior diameter of the crown—by the great prominence of the primary ridge (*n*)—by the breadth of the vertically convex surface of the fang—by the width of the lateral facets—and by the contraction of the internal or vertically concave surface which becomes ridge-like below.

"The anterior and inferior serrated edge is rapidly recurved towards the blunt excentric apex, and forms above an obtuse prominent angle with the upper segment of that border, which is striated, and everted as it were by the encroachment of the anterior deeply concave lanceolate facet impressing the lower portion of the crown

and fang. The broad area between it and the primary ridge, exhibits numerous striæ of enamel converging as they descend to a secondary ridge; on the crest of which, one is prolonged before the outer edge of an anterior apical serration. The posterior coronal margin is nearly straight, plain above, and serrated below. The primary ridge forms a strong convex buttress subsiding towards each extremity; it is slightly inclined to the hinder edge, and nearly obliterates the smaller posterior area.

"From the inversion of the teeth in the upper jaw, we naturally expect to find some alteration in the configuration of the molars; while the position of the apex, of the primary ridge, and of the areas into which it subdivides the crown, will remain as in the lower series. On these grounds I am led to conclude that the smaller area always indicates the posterior part of the tooth, whether of the upper or lower jaw; but the marginal angle and the reflected edge are anterior in the upper molars, and posterior in the lower, these characters having relation to the manner in which the series of teeth are arranged. In the lower jaw the posterior margin of the molar overlaps, or rather projects internally beyond the anterior edge of the tooth behind, but in the upper it is situated externally to it (Xylographs, No. 3 and 4, page 193.); a similar arrangement takes place in the Ruminants. The mechanical advantages resulting from the opposite curvature of the teeth in the upper and lower jaw, are too obvious to require comment."

As it is very rarely that a specimen occurs in which the absorption of the fang, from the upward growth and pressure of a new tooth, has not taken place in a greater or lesser degree, it is probable that the formation of successional teeth was in constant progress at all periods of the animal's existence, as is the case in most of the Saurian reptiles.

The internal structure of the teeth is in striking accordance with the external form and mechanical arrangement of the dental organs; for the central body of dentine or tooth ivory is of a softer and coarser texture than in any other known Saurian, and closely resembles that observable in the colossal vegetable feeders of the Sloth tribe—the Mylodon and Megatherium*. But towards the periphery of the anterior part of the tooth the dentine is finer and harder; and not only the front of the crown, but also the inserted base, is covered by a thick layer of enamel; and from this peculiar arrangement of substances of different degrees of hardness, the tooth, in every stage, must have been admirably adapted for the trituration and comminution of vegetable food. A vertical slice of a tooth, showing the pulp-cavity, with the dentine traversed by vascular canals radiating from the centre, and running parallel with the calcigerous tubes, is represented as seen by transmitted light, and magnified eight diameters, in Plate XVIII. fig. 3.

The dental pulp becomes ossified in the old teeth, so that whatever the degree of abrasion, the exposed masticating coronal surface is solid; this is seen even in the

* "The intimate structure of the vascular dentine of the Bradypus resembles that of the inner half of the dentine of the Iguanodon."—*Odontography*, p. 329.

last stage, when the crown is reduced to a mere plate of dentine, as in the specimen previously figured (Xylograph, No. 2, *ante*, p. 188)*.

As the articular piece which contains the socket of the lower jaw for receiving the inferior head of the *os quadratum* is unfortunately wanting, the mechanism of the articulation can only be conjectured; for although several examples of the tympanic bone —which in reptiles as in birds connects the lower with the upper maxilla—are preserved in my former collection, neither of the specimens is sufficiently perfect to indicate the precise mechanism of the joint. One of the tympanic bones found in the same quarry with teeth and bones of the Iguanodon, and which I am led to consider as having belonged to that reptile, is 6 inches high and 5½ inches wide; it consists of a thick pillar, which is contracted at the sides in its vertical direction, and has two thin expanded lateral processes; it terminates both above and below in an elliptical and nearly flat surface; it is very cavernous from the large size of the tympanic cells. This bone differs considerably from the corresponding element in the Iguana, the peculiarity, doubtless, having relation to some modification in the mechanism of the lower jaw, by which the more complete comminution of vegetable substances was effected, than by maxillary organs constructed after the usual Saurian type.

Physiological inferences.—In instituting a comparison between the maxillary organs above-described, and those of the existing herbivorous lizards, with a view of obtaining some physiological deductions from the peculiar osteological characters of the fossil remains, we are at once struck with their remarkable deviation from all known types in the class of reptiles. In the *Amblyrhynchi*, the most exclusively vegetable feeders of the Saurian order, the alveolar process beset with teeth is continued round the front of the mouth; the junction of the two rami of the lower jaw at the symphysis presenting no edentulous interval whatever, and the lips are not more developed than in other reptiles: in the Iguanas, as shown in my former memoir, the same character exists. In the carnivorous Saurians the teeth are also continued to the symphysial suture on each side. The extinct colossal lizards offer no exception to this rule; in the acrodont Mosasaurus of the Chalk, and in the thecodont Megalosaurus of the Oolite and Wealden, the jaws are armed with teeth to the anterior extremity. In short, the edentulous, expanded, scoop-shaped, procumbent symphysis of the lower jaw of the Iguanodon has no parallel among either existing or fossil reptiles; and we seek in vain for maxillary organs at all analogous, except among the herbivorous Mammalia. The nearest approach is to be found in certain *Edentata* —as for example in the *Cholœpus didactylus* or Two-toed Sloth, in which the anterior part of the lower jaw is edentulous and much-prolonged: the correspondence is still closer in the gigantic extinct *Mylodons*; in which the symphysis resembles the blade of a spade used by turf-diggers, and has no traces of incisive sockets; and were not this part of the jaw elevated vertically in front, and the rami confluent, it would pre-

* For a detailed account of the microscopical structure of the teeth of the Iguanodon, see "Odontography, or a Treatise on the Comparative Anatomy of the Teeth," by Professor Owen, p. 246–253.

sent the very counterpart of that of the Iguanodon. This striking resemblance will be obvious to any one who will compare the illustrations subjoined to this memoir, with the magnificent specimen of the *Mylodon robustus* in the Hunterian Museum*.

The great size and number of the vascular foramina distributed along the outer side of the dentary bone and beneath the border of the symphysis (Plate XVI. fig. 2, and Plate XVII. fig. 4), and the magnitude of the anterior outlets which gave exit to the vessels and nerves that supplied the front of the mouth, indicate the great development of the integuments and soft parts with which the lower jaw was invested†.

The sharp ridge bordering the deep groove of the symphysis, in which there are also several foramina, evidently gave attachment to the muscles and integuments of the under lip; and there are strong reasons for supposing that the latter was greatly produced, and capable of being protruded and retracted, so as to constitute in conjunction with a large fleshy prehensile tongue, a powerful instrument for seizing and cropping the leaves and branches, which, from the construction of the teeth, we may infer constituted the chief food of the Iguanodon.

Thus we find the mechanism of the maxillary organs of the Wealden herbivorous Saurian, as elucidated by recent discoveries, in perfect harmony with the remarkable dental characters which rendered the first known teeth so enigmatical to the palæontologist, and another interesting proof is obtained of the constancy of those laws by which the correlation of organic structures is governed.

In the Iguanodon we have a solution of the problem how the integrity of the type of organization peculiar to the class of cold-blooded Vertebrata was maintained, and yet adapted, by slight and simple modifications, to fulfil the conditions required by the economy of a gigantic terrestrial reptile, destined to obtain support exclusively from vegetable substances; in like manner as the extinct colossal herbivorous Edentata which flourished in South America, ages after the Country of the Iguanodon and its inhabitants had been swept from the face of the earth.

Thus in the unlimited production of successional teeth at every period of the animal's existence, in the mode of implantation of the teeth, and in the composite structure of the lower jaw—each ramus consisting of six distinct elements—the Saurian type of organization is unequivocally manifest; while the intimate structure of the dental organs corresponds with that of the Sloths, and the subalternate arrangement and reversed position of the upper and lower series of teeth, with that of the Ruminants. And again, the edentulous and prolonged symphysis, and the great develop-

* In the *Mylodon Darwinii* the rami of the lower jaw anterior to the teeth are contracted vertically, and converge to a longer and narrower symphysis, which is inclined forwards at a more open angle with the horizontal ramus, than in the *Mylodon robustus*; and therefore still more nearly approaches that of the Iguanodon. See Professor Owen on the Mylodon.

† The external vascular foramina are remarkably augmented in the dentary bone of the Iguanodon as compared with other reptiles. In the colossal Mosasaurus, the dentary piece of a jaw 4½ feet long, has but ten or twelve relatively small foramina; in the Iguana but five or six; in the Monitors six; in the Crocodiles they are numerous, but small and irregular. In the Megalosaurus there are four foramina, and several small ones.

ment of the lower lip and the integuments of the jaws, as indicated by the size and number of the vascular foramina, present a striking analogy to the Edentata, with which indeed other parts of the osteology of the Iguanodon bear a remarkable resemblance; as for example, the sacrum formed by the anchylosis of five vertebræ, the expanded vertebral portion of the ribs, &c.; while the massive femur with its medullary cavity, well-marked trochanters and condyles, and the short and strong metatarsal and phalangeal bones, remind us of the gigantic recent pachyderms.

In fine, we have in the Iguanodon the type of the terrestrial herbivora, which in that remote epoch of the earth's physical history, termed by geologists "*The Age of Reptiles*," occupied the same relative station in the scale of being, and fulfilled the same general purposes in the economy of nature, as the Mastodons, Mammoths, and Mylodons of the tertiary periods, and the large pachyderms of modern times.

Although many important characters of the osteology of the Iguanodon are still unknown, we may, I conceive, from the data hitherto obtained, safely infer that this gigantic herbivorous reptile was equal in bulk to the Elephant, and as massive in its proportions; for living exclusively on vegetables there must have been a large development of the abdominal region. Its limbs must have been of proportionate size to sustain and move so enormous a carcass. The hinder extremities in all probability presented the unwieldy contour of those of the Hippopotamus and Rhinoceros, and were supported by strong short feet, protected by broad horny ungual phalanges. The fore-legs appear to have been less bulky, and adapted for seizing and pulling down plants and branches of trees. The teeth and jaws demonstrate its power of mastication and the nature of its food; and the remains of coniferous trees, arborescent ferns and cycadeous plants, with which its relics are commonly associated, indicate the character of the flora adapted for its sustenance.

I forbear entering at this time upon other considerations relating to the fossil reptiles of the Wealden, in the hope of being able to lay before the Royal Society, on some future occasion, an account of several other interesting Saurian remains from the strata of Tilgate Forest; but I beg to subjoin the following supplementary remarks on my last memoir.

Regnosaurus Northamptoni, Phil. Trans. 1841, Plate V. figs. 1, 8.—The portion of the lower jaw of a Saurian formerly described as that of a young Iguanodon*, is proved by the specimen discovered by Captain Brickenden, to be generically or subgenerically distinct from the *I. Mantelli*, although unquestionably belonging to the same remarkable family of herbivorous reptiles; and the internal structure of the teeth in this specimen, so far as I can judge from a microscopical examination of a very small fragment from the upper part of the fang, corresponds more nearly with that of the Iguanodon than with the very fine and dense tooth-ivory of the teeth of

* Philosophical Transactions, 1841, p. 131.

the Hylæosaurus. I therefore propose to distinguish this fossil Saurian by a name indicative of the district from which, in common with so many relics of the same class, it was obtained—*Regnosaurus**; with the specific appellation of *Northamptoni*, as a tribute of respect to the eminent nobleman whose approaching retirement from the Presidency of the Royal Society is so much to be regretted.

19 *Chester Square, Pimlico,*
May 24, 1848.

Description of the Plates.

PLATE XVI.

A considerable portion of the right ramus of the lower jaw of an adult Iguanodon from the Wealden sandstone of Tilgate Forest, discovered by Capt. Lambart Brickenden, F.G.S. The figures are of the size of the original.

Fig. I. The inner or mesial aspect.

a. The coronal germ of the first anterior tooth, in its alveolus.

b. The crown of a successional tooth in its natural situation.

c. Portion of the base of a successional tooth. The above are visible in consequence of the removal of the inner parapet of the alveolar process.

d, d. The deep elongated *opercular furrow*, originally covered by the splenial or opercular bone.

e. An obtuse tubercle or projection forming the anterior termination of the symphysial portion of the jaw.

f, f, f. Denote some of the alveoli or sockets of the mature molar teeth.

m. The coronoid or complementary bone.

s. The articulating surface forming the symphysial suture.

Fig. II. An oblique external view of the same specimen. In this figure the coronoid process (*m* of fig. 1) is not delineated, and the fractured posterior end of the fossil is represented to show the situation of the great dental canal (*g*), and the thickness of the parietes of the bone; the internal course of this canal is exposed by the fracture (*h*).

PLATE XVII.

Fig. I. Outline of the anterior part of the lower jaw of the Iguanodon, seen from above; reduced one-half the natural size in linear dimensions.

s, s. The symphysial suture.

e, e. The mental tubercle.

* *Sussex Saurian*; the County of Sussex was anciently inhabited by the *Regni*.

Fig. II. Outline of the under or inferior aspect of the same.

l. l. Area for the attachment of the protractor muscles of the tongue.

e, e. The mental tubercle.

Fig. III. Section presented by the posterior fractured end of the specimen (see Plate XVI. fig. 2); reduced half linear.

1, 1. The outer wall or parapet of the alveolar process.

2. Remains of the inner or mesial alveolar parapet.

3. Posterior section of the great dental canal; the lesser foramen indicates the channel for the vessels sent off from the main trunk to supply the dental germs.

4. The *opercular furrow.*

Fig. IV. The external aspect of the specimen represented in Plate XVI., reduced one-half in linear dimensions. In this view the numerous vascular foramina leading from the dental canal are distinctly shown; they extend in a line parallel with the alveolar margin, and are continued to the anterior extremity of the symphysis; one large foramen being situated immediately under the mental tubercle (*e*).

e. The mental tubercle forming the anterior extremity of the symphysis.

h. A fracture on the side of the bone, by which the course of the great dental canal is exposed to view.

i. An eminence at the commencement of the anterior edentulous portion of the jaw.

k. A deep groove beneath the margin of the symphysis.

m. The coronoid process.

PLATE XVIII.

Teeth of the Iguanodon.

Fig. 1. A molar tooth belonging to the left side of the upper jaw, having the crown worn by use: from Tilgate Forest.

1. The outer or external aspect, showing the ridged and enamelled surface of the crown.

1^a. Lateral view of the tooth.

1^b. Surface of the crown worn smooth by mastication, and presenting two distinct facets (1 and 2), produced by the attrition of the corresponding lower molars.

f. The fang.

n. Marks the primary ridge.

Fig. 2. Upper molar of the left side, in which the crown of the tooth is much abraded

and the fang in a great measure absorbed, from the downward growth of a successional tooth.

2. The enamelled and ridged external aspect of the crown.

2^a. The smooth convex inner aspect of the same.

2^b. The abraded coronal surface with its double facets (1 and 2).

a. Anterior margin.

b. Posterior marginal angle.

f. Remains of the fang, showing the cavity produced by a successional germ.

n. Primary ridge.

Fig. 3. Vertical section of the crown of an unused tooth, seen by transmitted light, magnified eight diameters.

e. Enamel.

d. Vascular dentine.

p. Pulp-cavity filled with mineral matter.

Fig. 4. A successional tooth of the right side of the lower jaw, with the serrated coronal margin entire, from Brook Point, Isle of Wight. This specimen is identical with the tooth in place (Plate XVI. fig. 1), but must have belonged to a larger individual.

4. The mesial or inner aspect.

a. The anterior margin.

b. The posterior marginal angle.

n. The primary ridge of the enamelled front of the crown.

4^a. The external smooth convex aspect of the same.

p. Pulp-cavity.

Fig. 5. A tooth belonging to the left side of the lower jaw; the apex of the crown partially worn away. This specimen, together with figs. 1, and 4, with numerous vertebræ, a femur $3\frac{1}{2}$ feet long*, and other bones, were obtained from the Weald Clay, forming the cliff near Brook Point, Isle of Wight; the whole probably belonged to the same individual, which must have been an aged reptile of very colossal proportions†.

5. The smooth, convex, outer aspect.

5^a. Oblique view, showing the posterior side and marginal angle, and the ridged enamelled inner surface.

a. The anterior margin.

b. The posterior marginal angle.

f. The fractured extremity of the fang exposing the pulp-cavity (*p*).

Fig. 6. Molar of the left side of the lower jaw: in this example the whole of the

* I have presented this bone to the Hunterian Museum.

† See my Geology of the Isle of Wight, p. 315.

serrated part of the crown is worn away, and the fang absorbed by the pressure of a successional tooth.

6. The smooth convex outer aspect; the worn surface of the crown has two distinct facets, as in the abraded coronal planes of figs. 3 and 4.

6*. The inner or mesial aspect of the same.

PLATE XIX.

A portion of the anterior part of the left upper maxillary bone of an adult Iguanodon, from Tilgate Forest: represented of the size of the original*.

Fig. I. The inferior or alveolar aspect, showing the remains of the sockets of ten molars.

f, *f*. Dental alveoli.

x. The intermaxillary articulating surface.

Fig. II. The upper or nasal surface, with deep channels for the infra-orbital vessels and nerves.

a, *a*. The infra-orbital canal.

b. Retrograde furrow of the same.

c. A deep concavity in the roof of the infra-orbital canal (see description, *ante*, p. 191).

x. The anterior marginal surface that articulated with the intermaxillary bone.

* This specimen is in the British Museum.

*** The nearly perfect tooth figured in Philosophical Transactions, 1841, Plate VI. figs. 1, 2, 3, is an upper molar of a very young Iguanodon. Fig. 4 of the same plate is the coronal germ of an upper tooth.

XIV. *Determinations of the Magnetic Inclination and Force in the British Provinces of Nova Scotia and New Brunswick, in the Summer of* 1847.

By Professor GEORGE W. KEELY, *of Waterville College, Maine, United States.*
Communicated by Lieut.-Colonel SABINE, *For. Sec. R.S.*

Received March 1,—Read April 6, 1848.

IN an excursion in the provinces of Nova Scotia and New Brunswick in August and September 1847, I took with me some magnetical instruments, with which I made a few observations for determining the magnetic intensity. The observations were of two kinds; those for the relative total force, made with a pair of LLOYD needles, which I shall designate L(1) and L(2), and an inclination circle, seven inches in diameter, with two verniers reading to single minutes, constructed by BARROW, successor to ROBINSON; and those for the absolute horizontal force, made with a unifilar magnetometer by JONES. The positions of the needles in the inclination circle are determined by two reading microscopes with micrometer scales. The unifilar has a theodolite base and circle of six inches, divided on silver, and reading to twenty seconds. Both instruments are described in Captain RIDDELL's "Supplement" to his "Magnetical Instructions." Observations to determine the temperature coefficients of the LLOYD needles were made in a small building fastened with nothing but copper, and containing a copper stove. For the weights sent by the maker with these needles, which were inconvenient, I substituted two platinum weights, which have never been removed from the holes in which they were placed before my observations commenced. Using t, t', v, v', θ, θ', φ, φ' for the temperatures, the angles of deflection, the inclinations, and the relative forces, respectively, at low and high temperatures, the following Table exhibits the observations and results by the well-known formula $\varphi = \frac{\cos v}{\sin(\theta + v)}$. I find the results the same whether the mean values of t, v, and θ, &c. are used to obtain φ and φ', or a mean of the daily results is taken.

Table I.

Observations for the Temperature Coefficient of L(2). Waterville Mean Time.

Low temperatures.					High temperatures.				
1847.	t.	v.	θ.	φ.	1847.	t'.	v'.	θ'.	φ'.
d h					d h				
Feb. 10	28·1	26 26 35$\frac{1}{2}$	75 55 57$\frac{1}{4}$	0·9166800	Feb. 10	73·1	26 59 46$\frac{1}{2}$	75 55 57$\frac{1}{4}$	0·9142133
18 20·4	11·4	26 16 33$\frac{1}{2}$	76 02 14	0·9177840	20 00·5	70·0	27 11 41	75 56 45$\frac{1}{2}$	0·9133754
19 20·3	14·8	26 18 13$\frac{1}{2}$	75 56 45$\frac{1}{2}$	0·9173431	21 23·7	64·5	27 15 33$\frac{1}{2}$	75 56 17$\frac{1}{2}$	0·9130579
21 20·5	17·6	26 39 35	75 56 17$\frac{1}{2}$	0·9157335	22 23·7	60·5	27 09 20$\frac{1}{2}$	76 00 58$\frac{1}{2}$	0·9138112
22 20·5	15·6	26 24 20$\frac{1}{2}$	76 00 58$\frac{1}{2}$	0·9171375	23 23·7	84·2	27 50 06$\frac{1}{2}$	75 55 26$\frac{1}{2}$	0·9104202
23 20·7	34·1	26 59 42$\frac{1}{2}$	75 55 26$\frac{1}{2}$	0·9141865	26 00·3	80·6	27 38 39$\frac{1}{2}$	75 56 16$\frac{1}{2}$	0·9113319
25 21·3	33·5	26 52 51$\frac{1}{2}$	75 56 16$\frac{1}{2}$	0·9147465	27 00	73·3	27 38 46$\frac{1}{2}$	75 57 38$\frac{1}{2}$	0·9114102
26 21·3	25·6	26 59 49$\frac{1}{2}$	75 57 38$\frac{1}{2}$	0·9143125	28 23·7	69·7	27 27 59$\frac{1}{2}$	76 00 01$\frac{1}{2}$	0·9123667
28 20·5	35·4	27 00 01$\frac{1}{2}$	76 00 01$\frac{1}{2}$	0·9144437	Mar. 1 23·5	67·7	27 26 27$\frac{1}{2}$	75 57 30$\frac{1}{2}$	0·9123212
Mar. 1 20·5	31·0	26 56 56	75 57 30$\frac{1}{2}$	0·9145187	Feb. 18 23·5	62·3	27 04 12$\frac{1}{2}$	76 02 14	0·9142698
Means.....	24·51	26 41 27$\frac{1}{2}$	75 57 54$\frac{1}{2}$	0·9156886	Means.....	70·49	27 22 15$\frac{1}{2}$	75 57 54$\frac{1}{2}$	0·9126578
Calculated value from means of t, v, and θ ..... 0·9156908					Calculated value from means of t', v', and θ'..... 0·9126596				

Observations for the Temperature Coefficient of L(1). Waterville Mean Time.

Feb. 7 20·5	29·9	35 55 26$\frac{1}{2}$	75 54 21$\frac{1}{2}$	0·8723502	Feb. 8 03	75·1	36 11 41$\frac{1}{2}$	75 54 21$\frac{1}{2}$	0·8710132
8 20	31·9	36 00 08$\frac{1}{2}$	75 57 55	0·8723284	9 02	86·9	36 23 47$\frac{1}{2}$	75 57 55	0·8703828
9 20	34·2	35 59·36$\frac{1}{2}$	75 56 05$\frac{1}{2}$	0·8721856	10 01	78·3	36 15 45$\frac{1}{2}$	75 56 05$\frac{1}{2}$	0·8708558
10 20	32·6	35 52 53$\frac{1}{2}$	75 58 51$\frac{1}{2}$	0·8730186	10 23	78·8	36 16 50	75 58 51$\frac{1}{2}$	0·8710536
11 20·5	24·0	35 51 37$\frac{1}{2}$	76 00 06$\frac{1}{2}$	0·8732486	12 01	74·8	36 15 36$\frac{1}{2}$	76 00 06$\frac{1}{2}$	0·8712842
12 20	25·9	35 53 28$\frac{1}{2}$	75 58 32$\frac{1}{2}$	0·8729382	13 00	74·3	36 13 11$\frac{1}{2}$	75 58 32$\frac{1}{2}$	0·8713204
14 20·5	16·7	35 44 27$\frac{1}{2}$	75 58 34$\frac{1}{2}$	0·8736786	14 23	63·0	36 13 38$\frac{1}{2}$	75 58 34$\frac{1}{2}$	0·8712866
15 20·5	7·0	35 44 33$\frac{1}{2}$	75 58 24$\frac{1}{2}$	0·8736534	15 23	71·0	36 18 04$\frac{1}{2}$	75 58 24$\frac{1}{2}$	0·8709048
16 21	19·0	35 54 58$\frac{1}{2}$	75 58 04$\frac{1}{2}$	0·8727674	16 23·5	75·7	36 24 26$\frac{1}{2}$	75 58 04$\frac{1}{2}$	0·8703469
18 20·7	15·0	35 57 57$\frac{1}{2}$	76 02 14	0·8729488	19 00·7	67·8	36 29 45$\frac{1}{2}$	76 02 14	0·8705426
19 20·7	20·4	35 55 41$\frac{1}{2}$	75 56 45$\frac{1}{2}$	0·8725744	20 01	81·0	36 28 25	75 56 45$\frac{1}{2}$	0·8698804
Means.....	23·33	35 53 42$\frac{1}{2}$	75 58 10$\frac{1}{2}$	0·8728811	Means.....	75·15	36 19 12	75 58 10$\frac{1}{2}$	0·8707882
Calculated value of φ from means of t, v, and θ 8728810					Calculated value of φ' from means of t', v', and θ'...0·8707881				

whence by the formula $q=\frac{\varphi-\varphi'}{\varphi'(t-t')}$ we have for L(1) the coefficient ·0000463; and for L(2) the coefficient ·0000722.

The values of θ in the above observations were obtained by the two dipping-needles accompanying the Lloyd needles, and which I shall call A(1) and A(2). The observations were made in the usual way with poles direct and reversed, in each case the marked limb of the circle facing both east and west; each single reading being a mean of from four to eight, successively obtained by lifting the needle from its agate supports by the lifting frame. The mean of the whole is, for A(1), twenty complete observations, 75° 57′ 03″; for A(2), nineteen complete observations, 75° 58′ 50″; whence the mean dip for Waterville (lat. 44° 33′ N., long. 293° 23′), Feb. 17, 1847, is 75° 57′ 56½″. Between June 14th and June 30th I made at the same place, with each of the needles, six complete observations, on as many days, and when, from the less variations of temperature, the adjustments were more under control; the results were for A(1), 75° 56′ 27″; for A(2), 75° 59′ 31″; mean dip for June 22nd, 75° 57′ 59″. In all my observations with these dipping-needles, up to the time of my excursion, I had observed far greater irregularities in A(2) than in A(1); in this last set, for instance,

the greatest difference between any partial result by A(1) and the mean dip was 01′·7, while for A(2) it was 03′·2; the difference for A(1) indeed was, in two-thirds of the results, less than 1′. Though this might not affect the means of a great number of observations, it is evident that if the observer is limited to one observation with each of these needles, he is far more likely, setting aside the effects of carelessness, to obtain a truly comparable value of θ by needle A(1) alone, than by a mean of the two. I have therefore confined my observations for θ, on my tour, with one exception, to A(1). The direction of the meridian has always been obtained with A(1), by considering the meridian as 90° from a mean of the positions of the vertical limb of the circle, when the needle resting on its supports had an inclination of 90° with its marked face alternately north and south. Moreover, in all my observations with the dipping or force needles, whenever the instrument was newly placed, the adjustments for correct position of the microscopes, the axis, the level, and the planes of support, were duly made if necessary. Table II. gives the details of the observations made in the provinces for v and θ with the logs of φ, by each needle reduced to 50° Fahr.

TABLE II.

No. for reference	Place.	Date. 1847.	Latitude to nearest minute.	Longitude to nearest minute.	For inclination. Needle.	Poles direct.	Poles reversed.	θ.	Observations with Lloyd needles. Needle.	Temp. Fahr.	v.	Logarithms of φ.
												Means used.
1.	Halifax, N.S.	Aug. 20.	44° 39′	298° 23′	A(1)	75° 37′	75° 37′·1	75° 37′	L(1)	77°·3	39° 32′·1	1·9310218
	Halifax, N.S.	21.			A(1)	75 37·6	75 38·3	75 37·9	L(1)	77·5	39 32·5	
	Halifax, N.S.	21.							L(2)	76·9	32 15·1	1·9495554
2.	Hiltz's, N.S.	23.	44 57	295 9	A(1)	75 37	75 37	75 37	L(1)	74·0	39 36·5	1·9307381
3.	Windsor, N.S.	24.	45 10	295 44	A(1)	75 40·6	75 42·2	75 41·4	L(1)	76·8	39 38	1·9309837
4.	Kentville, N.S.	25.	45 12	295 14	A(1)	75 45·1	75 46·3	75 45·7	L(1)	52·1	39 09·6	1·9320107
5.	Bridgetown, N.S.	26.	44 51	294 22	A(1)	75 40·9	75 41·9	75 41·4	L(1)	75·3	39 05·2	1·9323155
6.	Annapolis, N.S.	27.	44 45	294 04	A(1)	75 41·7	75 41·2	75 41·5	L(1)	68·5	38 58·8	1·9325703
	Annapolis, N.S.	27.							L(2)	70·3	31 41·2	1·9508199
7.	St. John, N.B.	Sept. 1.	45 14	293 57	A(1)	75 55·7	75 55·7	75 55·7	L(1)	59·9	38 22·2	1·9348103
8.	Fredericton, N.B.	2.			A(1)	76 59·2	76 58·5	76 58·9	L(1)	72·0	39 19·7	1·9364098
9.	Woodstock, N.B.	4.	46 09	292 25	A(1)	77 12	77 10·2	77 11·1	L(1)	73·2	39 14·8	1·9373967
	Woodstock, N.B.							76 59·6				1·9377287
	Woodstock, N.B.	11.							L(2)	63·2	30 56·1	1·9553924
10.	Riviere des Chutes	6.	46 36	292 16	A(1)	77 11·1	77 11·7	77 11·4	L(1)	69·0	38 54·3	1·9381584
	Riviere des Chutes	11.							L(2)	45·3	30 37·8	1·9559425
11.	Grand Falls of St. John	7.	47 03	292 15	A(1)	77 28·1	77 31	77 29·5	L(1)	70·7	39 29·1	1·9379492
	Grand Falls of St. John	10.				77 27·5	77 31·6	77 29·5	L(2)	59·0	31 09	1·9561125
12.	Grand River	8.	47 11	292 03	A(1)	77 36·4	77 34·8	77 35·6	L(1)	49·2	38 51·4	1·9392578
	Grand River	8.							L(2)	61·4	31 01·6	1·9565685
13.	Madawaska	9.	47 22	291 41	A(1)	77 44·9	77 44·8	77 44·8	L(1)	65·1	39 09·3	1·9395932
	Madawaska	9.			A(1)				L(2)	77·6	31 08·7	1·9573159
	Madawaska	9.			A(2)	77 49·3	77 42	77 45·6				

Remarks on Table II.

1. This station was on the east side of Citadel Hill, in an enclosure surrounded with a picket fence, and as much as forty or fifty rods from the N.E. outer line of the works. There were no iron stores in the works, and only two or three guns mounted, which were on the S.W. side. To ascertain if there was local attraction, I took the dip again in the plain on the west side of the hill, at least 100 rods from the works, and found it did not vary by one minute.

2. On the hill, back of Hiltz's Tavern, half-way from Halifax to Windsor.

3. M^{c}Bride's Garden, one-fifth of a mile N. of the Catholic Chapel.

4. Garden, back of Terrey's Hotel.

5. Forty rods S.E. of Quirk's Tavern.

6. An open field back of Hall's Tavern, and about forty rods S. of Catholic Chapel.

7. On the sea-side E. of the Barracks.

8. River-side in front of the Province House.

9. In an open field, a few rods, say thirty, N. of the Woodstock Hotel. On examining my notes at home, I found that a somewhat thick pencil-mark, in noting the azimuths for meridian, had caused the observations for θ and v on the 4th to be made just 10° out of it: calling those angles θ' and v', θ' was reduced to the meridian by the formula $\cot\theta = \cot\theta' - \cos 10°$; I then obtained the value φ' from θ' and v', as if rightly observed; and then obtained φ from the equation $\varphi = \varphi' \frac{\sin\theta'}{\sin\theta}$, which, I believe, will be found a correct process.

10. In the road near Woolverton's.

11. Near the Barracks; needles unsteady on the 7th.

12. On the lower cape, at the junction with the St. John. Observations with L(1) disturbed.

13. On the lower cape, at the junction of the Madawaska with the St. John.

In regard to the latitudes and longitudes, I am indebted to Major Graham for those of Nos. 9, 10, 11, 12 and 13. Messrs. Crauford and Agnew, chronometer raters at Halifax and St. John respectively, furnished me with those for Nos. 1 and 7; the rest were obtained from the best authorities of books or maps that I could procure.

Table III. exhibits the change in force of needles L(1) and L(2); the results are reduced to a temperature of 50°.

Table III.

1847.	No. of observations.	φ for L(1).	Difference.	1847.	No. of observations.	φ for L(2).	Difference.
February 13.	22	·8718039	·0010902	February 23.	21	·9140079	·0069450
June .....17.	10	·8707137	·0000015	June .....30.	10	·9070629	·0002127
August ...16.	5	·8707122		August ...16.	5	·9068502	

From the above Table it is obvious that both needles lost considerable force between February and June, and that after that time L(2) continued to lose, while L(1) retained its force. I have therefore reduced all observations made with L(2) to the 30th of June, by considering the loss as proportional to the time, the coefficient of reduction being $(1+\cdot000005.d)$, d being the number of days after the 30th of June. Column (3.) in Table IV. contains the logarithms corrected in this manner for L(2), and those of L(1) as originally found. The numbers ·8707137 and ·9070629 are the values of φ *at Waterville* on the 30th of June by L(1) and L(2) respectively; if the factor 1·04175 which connects them is compared with the corresponding factors in column (4.) (omitting that for Grand River for a reason already stated), these factors will all be found to exceed it by a small quantity: waiving discussion, at present, on the cause of this difference, I shall assign half the difference between the mean of these factors and 1·04175, or 0·00036 as a correction common to both, positive for L(1) and negative for L(2), which, while it leaves the mean determinations where both needles were used unaltered, will secure a more just comparison for stating where but one needle was used. I believe the difference, however, has hitherto been considered wholly within the errors of observation. Column (5.) contains the corrected logarithms, that is, the values of φ for L(1) increased in the ratio of 1 to 1·00036, and those of φ for L(2) reduced in the same ratio. Column (7.) contains the total forces for both needles, considering ·8707137, or the number expressing the relative force by L(1) on the 30th of June at Waterville, as the unit of force; and column (8.) contains the means.

TABLE IV.

(1.) Station.	(2.) Needle.	(3.) Logarithms corrected for change of force in L(2).	(4.) Factors connecting the numbers corresponding to the logarithms (in col. 3) for L(1) and L(2).	(5.) Logarithms corrected for factor connecting L(1) and L(2).	(6.) Logarithms reduced to Waterville as unit.	(7.) Forces to Waterville unit.	(8.) Means.
Halifax	L(1)	$\bar{1}$·9310218	1·04387	$\bar{1}$·9311781	$\bar{1}$·9913028	·98017	·98081
Halifax	L(2)	$\bar{1}$·9496683		$\bar{1}$·9495120	$\bar{1}$·9918746	·98146	
Hiltz's	L(1)	$\bar{1}$·9307381		$\bar{1}$·9308944	$\bar{1}$·9910191	·97953	·97953
Windsor	L(1)	$\bar{1}$·9309837		$\bar{1}$·9311400	$\bar{1}$·9912647	·98009	·98009
Kentville	L(1)	$\bar{1}$·9320107		$\bar{1}$·9321670	$\bar{1}$·9922917	·98241	·98241
Bridgetown	L(1)	$\bar{1}$·9323155		$\bar{1}$·9324718	$\bar{1}$·9925965	·98310	·98310
Annapolis	L(1)	$\bar{1}$·9325703	1·04322	$\bar{1}$·9327266	$\bar{1}$·9928513	·98367	·98401
Annapolis	L(2)	$\bar{1}$·9509458		$\bar{1}$·9507895	$\bar{1}$·9931521	·98436	
St. John	L(1)	$\bar{1}$·9348103		$\bar{1}$·9349666	$\bar{1}$·9950913	·98876	·98876
Fredericton	L(1)	$\bar{1}$·9364098		$\bar{1}$·9365661	$\bar{1}$·9966908	·99241	·99241
Woodstock	L(1)	$\bar{1}$·9377287	1·04189	$\bar{1}$·9378850	$\bar{1}$·9980097	·99543	·99514
Woodstock	L(2)	$\bar{1}$·9555509		$\bar{1}$·9553946	$\bar{1}$·9977572	·99485	
Riviere des Chutes	L(1)	$\bar{1}$·9381584	1·04218	$\bar{1}$·9383147	$\bar{1}$·9984394	·99641	·99626
Riviere des Chutes	L(2)	$\bar{1}$·9561010		$\bar{1}$·9559447	$\bar{1}$·9983073	·99611	
Grand Falls	L(1)	$\bar{1}$·9379492	1·04308	$\bar{1}$·9381055	$\bar{1}$·9982302	·99593	·99621
Grand Falls	L(2)	$\bar{1}$·9562688		$\bar{1}$·9561125	$\bar{1}$·9984731	·99649	
Grand River	L(1)	$\bar{1}$·9392578	1·04102	$\bar{1}$·9394141	$\bar{1}$·9995388	·99894	·99823
Grand River	L(2)	$\bar{1}$·9567205		$\bar{1}$·9565642	$\bar{1}$·9989268	·99753	
Madawaska	L(1)	$\bar{1}$·9395932	1·04202	$\bar{1}$·9397495	$\bar{1}$·9998742	·99971	·99948
Madawaska	L(2)	$\bar{1}$·9574700		$\bar{1}$·9573137	$\bar{1}$·9996763	·99925	
Waterville	L(1)	.....	.....	$\bar{1}$·9398753	10·	1·	1·0000
Waterville	L(2)	.....	.....	$\bar{1}$·9576374	10·	1·	
Logarithmic factors used in the above changes.	L(1)	.....	.....	+·0001563	+·0601247		
	L(2)	.....	.....	−·0001563	+·0423626		

Observations with the Unifilar.

At Halifax, Kentville, Annapolis and Fredericton, I made observations with the unifilar; the magnet vibrated, and used also as a deflector, was marked H(10) and was a cylinder 2·953 inches in length; the deflected magnet was marked I(14), a cylinder 2·414 inches in length.

The magnet H(10) being suspended,—by turning the telescope through arcs of three or four degrees, and applying a correction for torsion, observed at the same times,—I obtained on the 27th of March for a scale division 10′·0999, and on the 29th 10′·0963; the value used is 10′·1.

Table V. exhibits the results of observations to determine the temperature coeffi-

cient of magnet H(10); and Table VI. shows the values of P from the formula $P=-\frac{r^2r'^5\sin u'-r'^2r^5\sin u}{r'^5\sin u'-r^5\sin u}$, using the distances 1 foot and 1·4 foot.

TABLE V.

April 29th and 30th.	·000160 ·000169 ·000158 ·000168
Mean.....	·000164

TABLE VI.

Date.	Values of P.
July 28.	—·00042
July 29.	—·00091
Sept. 25.	—·00157
Nov. 27.	—·00162
Dec. 8.	—·00102
Mean ...	—·00111

LAMONT's method was adopted of obtaining the moment of inertia of cylinder H(10) by means of a brass ring accompanying the instrument, whose dimensions were,—

	ft.
External diameter . .	0·2153
Internal diameter . .	0·1667
Weight*	

Whence $\log k'=\cdot5489695$.

The cylinder H(10) had on it, at the ends, two small brass rings, the contour of which I shortened by filing, so as to bear conveniently the metal ring in vibration. Twenty-one sets of vibrations without the ring, and eight sets with it, made between the 2nd and 6th of October, varying, in number of vibrations, from 340 to 466 each, and corrected for temperature, arc, torsion and rate of chronometer, all observed at the same times, gave for $\log \pi^2k$ at a mean temperature of 63°·3, 1·3320923. Observing, however, that the cylinder suspended seemed very slightly depressed at the N. end, I shifted the little ring there to the S. end, putting it in contact with the other ring, and at such a distance from the end of the cylinder as I had calculated would give the same moment of inertia; and then on the 8th and 9th of October made more observations for π^2k, the particulars of which are in Table VII.

TABLE VII.

Date.	Civil reckoning.	Whole time.	Number of vibrations.	Time of one vibration.	Commencing arc.	Final arc.	Temperature.	Torsion for 90° in scale divisions.	Rate chron.	k.
	d h m				Sc. div.	Sc. div.	°		″	
Oct. 8	9 33 A.M.	1448·3572	330	4·38896	3·0	·4	56·5	·8725	—6·5	2·1743 by 1st set.
8	10 21 A.M.	2091·8929	294	7·11528	3·0	·9	54·5	1·1800	—6·5	
8	01 18 P.M.	1500·8215	342	4·38836	2·9	·7	65·4	·76	—6·5	2·1787 by 2nd set.
8	02 32 P.M.	2103·	296	7·10473	2·8	·1	65·75	1·065	—6·5	
8	03 17 P.M.	1490·7857	340	4·38466	3·0	·6	64·0	·69	—6·5	
9	01 00 P.M.	1501·	342	4·38889	2·9	·7	59·5	·55	—6·5	2·1766 by 3rd set.
9	01 55 P.M.	2217·2643	312	7·10662	2·9	·1	59·3	·945	—6·5	
9	02 53 P.M.	1499·0357	342	4·38314	2·9	·4	56·0	·6875	—6·5	
9	03 47	2228·8857	314	7·09836	2·7	·9	56·1	1·0925	—6·5	2·1764 by 4th set.
9	04 33	1523·4785	348	4·37781	3·0	·6	50·5	·795	—6·5	
										2·1765 mean value.

* Weight not stated in the MSS.—E. S.

These observations gave for the mean value of $\log k$, ·3377587, at a mean temperature of 58°·2, and hence $\log \pi^2 k = 1{\cdot}3320584$. If this value of $\pi^2 k$ is reduced to the temperature of 63°·3, by the formula $1+2e(t'-t)$, it gives 1·3320885, differing from the former observed value only ·0000038. Where in the table three observations are included in one set, the mean of the true corrected values of T for the first and third was taken and combined with T^v, so as in some degree to eliminate changes of force.

Table VIII. contains the uncorrected particulars of my observations of vibrations and deflections at Halifax, Annapolis and Fredericton, and those of vibration only at Kentville; with the nearest observations, before and after my tour, at Waterville.

Table IX. contains m, X, and the total force; a mean for the value of m at Kentville having been taken from the values at Halifax and Annapolis.

Table X. contains the total forces at the four stations obtained by the unifilar reduced to Waterville by the observations of the Lloyd needle L(1) at the same stations, in order to test the accuracy of the observations; an additional column shows the same comparison for the only two stations where the two Lloyd needles and unifilar were all used; in other words, having obtained the total force at, say, Halifax by the unifilar, and also the relative force by the Lloyd needles, and knowing also the relative force at Waterville by the Lloyd needles, and therefore the *ratio* of the force at Halifax to the force at Waterville by the Lloyd needles, I multiply the aforesaid total force at Halifax got by the unifilar by this *ratio*, and obtain the total unifilar force at Waterville, and so with the rest.

Table VIII.

Station.	Date.	Magnet.	u.	Temperature.	u'.	Temperature.	Time of one vibration.	Number of vibrations.	Temperature.	Commencing arc.	Final arc.	Rate of chron.	Torsion for 90° in sc. divisions.
			m s	°	m s	°			°	Sc. div.	Sc. div.	n	
Waterville ...	July 29.	H(10)	12 21·3	63·8	4 28·5	64·1	4·35021	548	66·4	6·5	1·1	.....	·8925
Waterville ...	30.	H(10)	12 21·6	67·6	.....	.....	4·35277	460	72·0	5·25	0·75	.....	1·009
Halifax	Aug. 21.	H(10)	.....	.....	4 26	64·9	4·34901	338	71·5	5·0	1·0	−8·5	·69
Kentville.....	24.	H(10)	.....	.....	.....	.....	4·36005	238	61·9	5·0	1·0	−8·5	·6018
Annapolis ...	27.	H(10)	.....	.....	4 26·2	65·0	4·35008	344	68·5	5·5	0·8	−8·0	·52
Fredericton...	Sept. 2.	H(10)	.....	.....	4 49	71·2	4·53733	344	72·5	4·9	0·7	−7·0	·7225
Waterville ...	25.	H(10)	12 10·9	61	4 24·9	60·4	4·37520	356	56·0	8·4	1·4	−6·2	1·01

In this Table u and u' are given to the nearest tenth of a minute, but in the calculations the value in seconds was employed.

Table IX.

Station.	Date.	Corrected angles of deflection.	Time of one vibration.	m.	X.	Total force.
Waterville	July 29.	12° 23′ 02″·5	4·34798	·34928	3·2536	13·4174
Waterville	29.	4 29 04·8		·34926	3·2538	13·4181
Waterville	30.	12 23 43·9	4·34901	·34937	3·2515	13·4086
Halifax	Aug. 21.	4 26 41·2	4·34457	·34799	3·2710	13·1757
Kentville.....	24.	.....	4·35914	*	3·2493	13·2112
Annapolis	27.	4 26 54	4·34777	·34787	3·2672	13·2198
Fredericton.....	Sept. 2.	4 49 58·7	4·53242	·34780	3·0071	13·3491
Waterville	25.	12 12 15·6	4·27832	·34437	3·2544	13·4207
Waterville	25.	4 25 19·8		·34441	3·2540	13·4192

Table X.

Halifax reduced to Waterville	13·442	13·435
Kentville reduced to Waterville	13·448	
Annapolis reduced to Waterville	13·439	13·437
Fredericton reduced to Waterville	13·451	
	13·445	13·436

XV. *On a new Case of the Interference of Light.*

By the Rev. Baden Powell, *M.A., F.R.S., F.R.A.S., F.G.S., Savilian Professor of Geometry in the University of Oxford.*

Received April 6,—Read May 18, 1848.

(1.) In the state of advance at which the theory of light has now arrived, a single case of interference directly explicable by the ordinary principles of undulations, even though occurring under new conditions, could hardly be deemed of sufficient importance to form the subject of a separate communication to the Royal Society.

But in the present instance though the case presented, in its more *general* features, is easily accounted for on the acknowledged doctrine of interference and retardation, yet it offers many particulars in its *details*, in reference to which such explanation is, at least, not equally obvious: while some points require for their elucidation investigations of a more extended character.

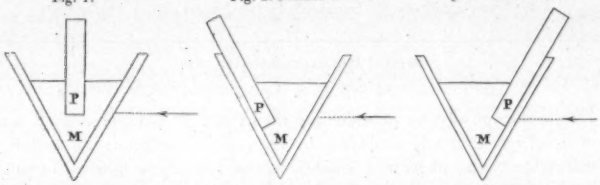
Again, it is found to be a case which by no means stands isolated, but offers analogies with other classes of phenomena which have excited considerable interest and discussion, especially with regard to what has been termed, perhaps improperly, a "polarity" in the prismatic rays,—a new instance of which is here exhibited. In these respects, then, I trust the subject may not appear unworthy of the notice of the Royal Society.

Having arrived at the primary results in July 1847, I communicated them to my friend Mr. G. G. Stokes of Pembroke College, Cambridge, who has gone extensively into the whole theory of these and other allied cases, and has afforded me much valuable aid in the investigation. In the present paper I propose only to describe my own experiments, with the general application of the undulatory theory to the explanation of them, supported by some numerical comparisons.

(2.) The main experiment is as follows:—in a *hollow glass prism*, or rather *trough*, containing some highly refractive and dispersive liquid, such as oil of sassafras, anise, or cassia, *a plate of glass is inserted* with its lower edge parallel to the edge of the prism, and so that its plane nearly bisects the angle of the prism, while it extends only through the upper half of the liquid, leaving the lower, or thinner part, clear (see fig. 1). Light being admitted through a narrow horizontal slit in the usual manner, *the spectrum thus formed is seen crossed by a number of dark bands parallel to the slit or edge of the prism.*

(3.) I have tried various combinations of oils and other media with plates of different thicknesses, both of glass and of other transparent substances. In these different instances some remarkable distinctions are exhibited. In some cases the bands are sensibly equidistant, in others increasing in number and fineness towards one

Fig. 1. Fig. 2. Position 1. Fig. 3. Position 2.



Arrangement I.

end of the spectrum: in most cases extending throughout, but in some deficient at one part.

(4.) With the same oil or medium, if the plate exceed a certain thickness, the bands become too numerous and fine to be seen: if less than a certain other limit, they become too few, broad and faint: and for some intermediate thickness they appear most vivid and distinct.

(5.) With plates and media of different refractive and dispersive powers as well as different thicknesses, changes in the number and vividness of the bands take place, as well as in the limits of their visibility, in a manner evidently dependent on the thickness and relative refractions jointly; though not in any such obvious relation as can be stated by a simple experimental law.

(6.) It is not *necessary* that the plate should have precisely the vertical position just described; if *inclined* either way, even to being in contact with either side of the prism, the bands are still seen; but they undergo a slight shifting downwards as the plate is inclined, and are perhaps less vivid (see figs. 2, 3).

(7.) Some combinations of a medium and a plate, such as glass with oils of turpentine or angelica, or water, &c., *give no bands with this arrangement.* But Mr. Stokes pointed out from theory, that in these cases bands might be expected to appear with a *reverse* arrangement; that is, by placing a narrow slip of glass, &c. to intercept the *thinner* part of the prism, leaving the upper or thicker part clear, and of course cutting off any portion of light, which might otherwise pass below the plate (see fig. 4, where *s* is a small screen for intercepting the light below).

Fig. 4.

Arrangement II.

On using such an arrangement for the cases just mentioned, I accordingly found bands produced.

(8.) In any case to see the bands well, especially towards the violet end of the spectrum, a strong light is requisite: that of the sun direct, shaded by a blue glass, or at least that of the bright part of the sky near the sun, was usually thrown in by the shutter apparatus; and though a small telescope was usually employed, yet the bands, in cases where they are vivid and broad, may be seen by the naked eye; and for such cases lamp-light may be used, but it will not suffice for the more delicate.

(9.) When *crystallized* substances are employed as *plates* other peculiar phenomena are presented.

A plate of calc-spar (formed by the natural cleavage) with oil of cassia gives two distinct sets of bands; the one finer and narrower than the other, which about the middle of the spectrum may be seen distinctly superimposed one on the other.

On applying a Nicol-prism each set disappears alternately, leaving the other visible at each quarter of a revolution of the analyser; showing them due to the two oppositely polarized pencils. It is easily ascertained that the *finer* bands belong to the *extraordinary*, the *broader* to the *ordinary ray*.

(10.) A plate of quartz, cut perpendicular to the axis, with oil of sassafras, gives very distinct bands, which may be seen to be in fact composed of two sets superimposed and nearly coinciding, since when the plate is inclined (as in position 1, see fig. 2) at intervals throughout the spectrum the near coincidence of the dark spaces of one set, with the bright of the other, occasions an extreme faintness in the bands. In this case the two pencils deviate sufficiently from the axis to approximate to plane polarized light, and thus the Nicol-prism causes the indistinctness to disappear at each quarter of a revolution by stopping one of them alternately.

(11.) For an *explanation* of the *general* phenomena of the formation of bands under the conditions specified, the simple interference-theory suffices.

Of the homogeneous pencil going to form any one ray of the spectrum, that half which passes through the thicker part of the prism is more retarded than that through the thinner; but uniformly, and in proportion to the difference of refraction, throughout the spectrum.

The plate of glass, however, having different indices for the several primary rays from those of the medium, interrupts this uniformity, and causes the one part of the pencil to be always retarded in an increasing ratio with respect to the other, throughout the spectrum; and as this difference of retardation amounts successively to an odd or an even multiple of a half wave-length, the rays will be in discordance or accordance, or give a dark or bright band accordingly.

(12.) But to account for the different conditions which determine the number and

character of the bands, and the limits of thickness, as well as which of the two arrangements before described, will produce them, it is necessary to consider more precisely the relative refractions of the plate and medium, or the amount and direction of the retardation; and it is found that on such considerations we obtain an expression which includes these conditions;—the difference of *sign* corresponding to the *two arrangements*: while it assigns the *number* of bands which will be formed between any two given rays, or throughout the whole spectrum, with a given thickness of the plate.

(13.) In the comparison of theory and observation, the broad facts,—that bands will be produced in the respective cases by the one or the other arrangement,—as well as their general character,—show an entire agreement with theory.

The more precise comparison of the *number* of bands formed throughout the spectrum, or within certain definite spaces of it, though in some cases unavoidably imperfect from the difficulty of distinguishing the bands, yet upon the whole gives accordances as good as perhaps can be expected.

(14.) When plates of doubly-refracting crystals are employed, the calculation for the extraordinary ray in particular directions in the crystal, becomes more complex, involving the laws of crystalline refraction.

In all cases a small error in the index causes a comparatively large difference in the calculated number of bands. But, from whatever cause, in these last instances the application of theory is, as yet, less satisfactory than in others; at least in the instance of calc-spar.

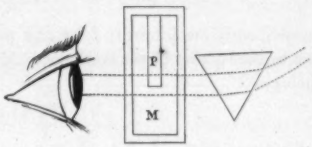
(15.) The first observation of the general phenomenon reminded me of the precisely *analogous* result obtained by Baron von Wrede, though in a manner so totally different*; in which two portions of light, unequally retarded the one by reflexion from the *first*, the other from the *second* surface of a plate of mica, impinge jointly on a prism, whence results a spectrum crossed with bands; while the author's profound analysis (founded on the hypothesis of the internal reflexions of a ray among the molecules of a medium) opens an extended analogy between these cases and those of the absorption of definite rays by media in general.

(16.) There is also obviously a general analogy between these phenomena and those observed by Mr. Fox Talbot and Sir D. Brewster, on partially intercepting the spectrum by a plate of mica covering half the pupil of the eye;—especially in the circumstance, that here also the plate must be applied towards *one side* of the prism, which corresponds to what has been described as a species of *polarity*. In those experiments the retardation is the difference of the retardations of the plate of mica and of a plate of air which would be contained between the surfaces of the mica produced: in mine it is the difference of the retardation of the glass and of an equal thickness of the liquid medium of the prism.

* Taylor's Foreign Scientific Memoirs, vol. i. part 3, p. 487.

(17.) Hence Mr. Stokes illustrated the case by supposing the glass plate inserted in a vessel with parallel sides filled with the medium; when if the spectrum formed by any prism were viewed through this combination, with the plate towards the thick part of the prism, the effect would be the same; and if the prism were of the same substance, the cases would be identical; the liquid prism in my experiment serving the double office of the prism and the flat vessel. (See fig. 5, where P is the plate and M the medium.)

Fig. 5.



(18.) Another remark here offers itself:—If it should be considered that the theory is sufficiently established to give confidence in deductions from it, it may be applied to the *inverse problem* of finding the refractive indices of a plate, those of the medium, and the number of bands, being known. This may be important for many substances which occur in the form of plates, but cannot be cut into prisms.

(19.) There remain also other features of the case to be accounted for, which, if slight in appearance, are yet not unimportant in a theoretical point of view; such as relate to the changes in the vividness of the bands, especially as affected by the thickness or inclination of the plate, by enlarging or contracting the aperture, or breadth of the prism,—and some other points,—to which the simple interference-theory cannot apply.

In all experiments of this kind it is now generally understood that there must be, theoretically at least, even if it be practically insignificant, another species of action concerned, dependent on *the diffraction of the lens*, whether that of the eye, or of the object-glass of the telescope, producing that "diffusion," as it has been termed, in the optical image, which, if of sensible amount, may influence the phenomena.

The method of investigating this species of action in general is equally well understood, though in some parts the theory has been found susceptible of improvement. In the present instance such an investigation is necessary to include some of the peculiar modifications of the phenomena observed; and this constitutes the subject of Mr. Stokes's researches, which he will give in a separate form.

The remainder of this paper is devoted to the details of the observations and the theoretical investigations.

Theoretical Investigation.

(20.) The intensity of the incident light being unity, and the direct vibration for any point in the spectrum being

$$\sin \frac{2\pi}{\lambda}(vt-x);$$

that for the part retarded by r will be

$$\sin\frac{2\pi}{\lambda}(vt-x-r);$$

or,
$$\sin\frac{2\pi}{\lambda}(vt-x)\cos\frac{2\pi}{\lambda}r-\cos\frac{2\pi}{\lambda}(vt-x)\sin\frac{2\pi}{\lambda}r.$$

Consequently the intensity I for any point of the whole resulting wave will be the sum of the squares of the coefficients of $(vt-x)$, or we shall find on squaring and reducing,

$$\mathrm{I}=2\left(1+\cos\frac{2\pi r}{\lambda}\right);$$

or if we assume $p=\frac{4r}{\lambda}$, it becomes

$$\mathrm{I}=2\left(1+\cos\frac{\pi}{2}p\right).$$

(21.) And if we suppose p to be originally an even number and to increase by unity for successive rays of the spectrum, we shall have the corresponding values,

p	$\cos\frac{\pi}{2}p=-1$, and therefore	$\mathrm{I}=0$
$p+1$	$=0$	$\mathrm{I}=2$
$p+2$	$=+1$	$\mathrm{I}=4$
$p+3$	$=0$	$\mathrm{I}=2$
$p+4$	$=-1$	$\mathrm{I}=0$
&c.	&c.	&c.

Thus for any two values p_1, p_2, if $p_1-p_2=4$, they correspond to a change from one dark band to another, and consequently, if for two rays $p_1-p_2=4n$, n will be the number of bands in the space comprised between those two rays: and if they be the extremes of the spectrum, n will be the whole number of bands. Its value may be assigned by considering the nature of the retardation, or obtaining an expression for r, as follows:—

(22.) On inserting the plate P of thickness τ whose index is μ_p, as above, into the medium whose index is μ_m, the retardation of the light which passes through the plate being the difference of the retardations of the plate and of an equal thickness of the liquid, will be expressed by

$$r=(\mu_p-\mu_m)\tau.$$

But since $\frac{p}{4}=\frac{r}{\lambda}$ (20.), we shall have

$$\frac{p}{4}=\left(\frac{\mu_p-\mu_m}{\lambda}\right)\tau.$$

And for any two rays whose indices are μ_1, μ_2, and wave-lengths λ_1, λ_2, we have

$$\frac{p_1-p_2}{4}=n=\left[\left(\frac{\mu_p-\mu_m}{\lambda}\right)_1-\left(\frac{\mu_p-\mu_m}{\lambda}\right)_2\right]\tau.$$

This formula may apply to the whole length of the spectrum, taking the two ex-

treme rays. And the thickness of the plate being known, we may find the number of bands by computing the coefficient in terms of μ and λ which are known.

(23.) Writing this coefficient $=q$ or $n=q\tau$, since here n is supposed a whole positive number, and q may be either $+$ or $-$ according to the values of μ and λ, we have,

$$\frac{n}{q}=\pm\tau.$$

Hence if, taking successive rays, we have always through the spectrum from the red to the violet,

$$\left(\frac{\mu_p-\mu_m}{\lambda}\right)_1<\left(\frac{\mu_p-\mu_m}{\lambda}\right)_2,$$

or the value of q negative, the effect of the plate will be such that the arrangement I. will give bands: if q be positive, the effect of the plate will be such that arrangement II. will give bands.

If for any combination of a plate and a medium $\left(\frac{\mu_p-\mu_m}{\lambda}\right)$ should have a *maximum* or *minimum* value at any ray, the difference would *change signs*, and bands be formed towards that end of the spectrum where it was $-$ with arrangement I.; and towards that end where it was $+$ with arrangement II.

(24.) The general principles of the "diffraction-theory," as applicable to the present case, are precisely the same as in Mr. Airy's paper*. But it will not be necessary here to go into the subject any further, since Mr. Stokes has greatly generalized and improved this theory so as to lead to other important results, the whole of which are discussed in his paper, in the present part of the Philosophical Transactions.

Observations.

(25.)

Arrangement.	Plate.	Medium.	Number of bands.				
	Glass.	Oil of Sassafras.	B to D.	D to F.	F to G.	G to H.	Total.
I.	inch. $\tau=\cdot5$ ·34 ·17 ·08 ·04 ·015	No bands visible. Very fine and close. Fine. Clear. Broad and clear. Very broad and faint.	6	14	21	24	65
II.		No bands.					
		(26.)					
		Oil of Cassia.					
I.	·08 ·04 ·015	Too fine to count. Fine.	15	29	32	Faint. 40?	116
II.		No bands.					

* Philosophical Transactions, 1841, Part I.

(27.)

Arrangement.	Plate.	Medium.	Number of bands.					
	Glass.	Oil of Cummin.	B to D.	D to E.	E to F.	F to G.	G to H.	Total.
I.	inch. $\tau = \cdot 04$	Broad.	0	0	5	11	Faint. 15?	31
II.		No bands.						

(28.)

		Oil of Turpentine.					
I.		No bands.					
II.	·08 ·04	Fine. Clear in the red; broader towards blue.	14	20	15	10	59

(29.)

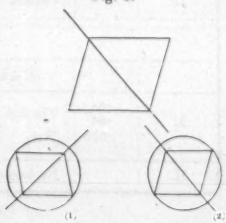
		Water.					
I.		No bands.					
II.	·04 ·015	Too fine to count. Fine and faint; difficult to count.	19	30?	22?	15?	86

(30.)

Arrangement.	Plate.	Medium.	Number of bands.			
	Calc-spar (by natural cleavage).	Oil of Cassia.	B to D.	D to F.	F to G.	G to H.
I.	inch. $\tau = \cdot 04$	Two sets of bands superposed.		Broad and faint.		
	Position vertical. With Nicol prism.	Broad set.	0	14	30?	40?
		Fine set.	20	36?	Too fine to count.	
	Position 1. Position 2.	Both sets broader. Both sets finer.				
	$\tau = \cdot 08$	Both sets too fine to count.				

(31.) To determine which set of bands belongs to the ordinary and which to the extraordinary pencil, we may proceed as follows:—Placing a rhomb of calc-spar with a small aperture behind it, so as to give two images, in the same relative position as the plate (see fig. 6) when the section of the Nicol-prism has its short diagonal perpendicular to that of the rhomb (1.), E disappears; when parallel (2.) O disappears. In the spectrum, in the former case the finer bands disappear, in the latter the broader. The fine bands therefore belong to E, the broad to O.

Fig. 6.



Or the same result might perhaps be deduced more directly from considering that as O is polarized parallel, and E perpendicular to the principal section, and that the *short* diagonal of the Nicol-prism is *horizontal* when light polarized by reflexion from an *horizontal* surface is *transmitted*,—or that the *short* diagonal is perpendicular to the plane of polarization of the *transmitted* ray. Then since when the short diagonal is perpendicular to the principal section of the calc-spar, the *fine* bands are stopped and the broad transmitted, it follows that the broad bands are polarized *parallel* to the principal section, or belong to O.

(32.)

Arrangement.	Plate.	Medium.	Number of bands.			
	Quartz cut perpendicular to axis.	Oil of Sassafras.	B to D.	D to F.	F to G.	G to H.
I.	inch. $\tau = \cdot 15$ Position vertical.	Bands fine and clear, broader towards red end	8	43	Too fine to count; estimated at 70?	80?
	Position 1 ..... Position 2	Bands rather finer.				

With the plate inclined in position 1, eight intervals of indistinctness (extending over four or five bands each) occur from H to about E; from E to D the bands altogether become very faint: perhaps two such intervals may be discerned: from D to B no bands appear. On applying a Nicol-prism, the intervals of indistinctness disappear at each quarter of a revolution.

Calculation.

(33.) In all the following calculations for n by the formula (22.), the values employed for the reciprocals of the wave-lengths of primary rays are as follows:—

Ray.	λ (decimals of 1 French inch).	$\frac{1}{\lambda}$.
B.	·00002541	39354
D.	·00002175	45977
E.	·00001945	51413
F.	·00001794	55741
G.	·00001587	63011
H.	·00001464	68306

The values of the term $\left(\frac{\mu_p - \mu_m}{\lambda}\right)\tau$ are interesting as expressing the absolute interval of route in wave-lengths of the two interfering rays, and thus, when compared with observation, conveying an idea of the extent to which the regularity of the undulations is kept up.

The indices here used are those contained in my "Report on Refractive Indices"*. For glass I have assumed the indices of FRAUNHOFER's crown glass, No. 9.

* British Association Report, 1839.

(34.) Glass and Oil of Sassafras, $\tau = \cdot 04$ inch.

Ray.	μ_p.	μ_n.	$\mu_p - \mu_n$.	$\frac{\mu_p - \mu_n}{\lambda}$	$\left(\frac{\mu_p - \mu_n}{\lambda}\right)\tau$.	Diff. = n.	Remarks.
B.	1·526	1·526	0	0	0		
D.	1·529	1·532	−·003	− 138	− 5·5	− 5	
F.	1·536	1·545	−·009	− 501	−20	−15	Hence in this case
G.	1·542	1·557	−·015	− 945	−37·8	−18	arrangement I. will
H.	1·546	1·569	−·023	−1571	−62·8	−25	give bands.
						−65	

(35.) Glass and Oil of Cassia (Report, No. ii.), $\tau = \cdot 015$ inch.

B.	1·526	1·594	−·068	− 2676	− 40		
D.	1·529	1·607	−·078	− 3586	− 54	− 14	
F.	1·536	1·636	−·100	− 5574	− 84	− 30	Here arrangement
G.	1·542	1·667	−·125	− 7867	−118	− 34	I. will give bands.
H.	1·546	1·702	−·156	−10656	−160	− 42	
						−120	

(36.) Glass and Oil of Cummin, $\tau = \cdot 04$ inch.

B.	1·526	1·502	+·024	+ 944	+37·7		
D.	1·529	1·507	+·022	+1011	+40·4	+ 2	
E.	1·533	1·513	+·020	+1028	+40·8	+ 1	Here arrangement
							II. would give bands
F.	1·536	1·520	+·016	+ 891	+35	− 6	from B. to E, and
G.	1·542	1·533	+·009	+ 567	+22·6	−12	arrangement I. from
H.	1·546	1·543	+·003	+ 205	+ 8	−14	E to H.
						−32	

(37.) We may remark that the indices for oil of cummin are all open to some uncertainty*, and it is easily found that a change in the indices of D and E of ·001 only would give *no bands* between B and E with either arrangement; for we should have on this supposition—

Ray.	μ_p.	μ_n.	$\mu_p - \mu_n$.	$\frac{\mu_p - \mu_n}{\lambda}$	$\left(\frac{\mu_p - \mu_n}{\lambda}\right)\tau$.	Diff. = n.	Remarks.
B.	.....	.....	.....	.....	+37·7		
D.	.....	1·508	+·021	+564	+38·5	0	No bands.
E.	.....	1·514	+·019	+976	+38·8	0	

(38.) Glass and Oil of Turpentine, $\tau = \cdot 04$ inch.

B.	1·526	1·470	+·056	+2203	+ 88		
D.	1·529	1·474	+·055	+2528	+101	+13	
F.	1·536	1·482	+·054	+3009	+120	+19	Hence arrangement
G.	1·542	1·488	+·054	+3402	+136	+16	II. will give bands.
H.	1·546	1·494	+·053	+3619	+145	+ 9	
						+57	

* See Report, British Association, 1839, p. 12.

(39.) Glass and Water, $\tau = \cdot 015$ inch.

Ray.	μ_p.	μ_m.	$\mu_p - \mu_m$.	$\frac{\mu_p - \mu_m}{\lambda}$.	$\left(\frac{\mu_p - \mu_m}{\lambda}\right)\tau$.	Diff. = n.	Remarks.
B.	1·526	1·331	+195	+ 7672	+115		
D.	1·529	1·333	+196	+ 9009	+135	+20	
F.	1·536	1·337	+199	+11092	+166	+31	Hence arrangement
G.	1·542	1·341	+201	+12663	+190	+24	II. will give bands.
H.	1·546	1·344	+202	+13796	+207	+17	
						+92	

(40.) Calc-spar and Oil of Cassia, ordinary ray. RUDBERG's indices.

Ray.	μ_{PO}.	μ_m.	$\mu_p - \mu_m$.	$\frac{\mu_p - \mu_m}{\lambda}$.	$\left(\frac{\mu_p - \mu_m}{\lambda}\right)\cdot\tau$ $\tau = \cdot 04$.	Diff.	Remarks.
B.	1·6531	1·5945	+·0586	+2306	+92		Hence with arrange-
D.	1·6585	1·6073	+·0512	+2353	+94	+ 2	ment I. there will
							be no bands from
F.	1·6680	1·6358	+·0322	+1794	+71	− 23	B to D, but bands
G.	1·6762	1·6671	+·0091	+ 573	+23	− 48	from D to H.
H.	1·6833	1·7025	−·0192	+1311	−52	− 75	
						146	

(41.) For the *extraordinary ray*, in a plate bounded by the planes of cleavage, Mr. STOKES has calculated the results as follows:—

"The incidence is supposed to be perpendicular; that is, strictly, the rays B, D, &c. are supposed to be received in succession at a perpendicular incidence: but the results may be applied with very little error to the case in which rays of mean refrangibility are incident perpendicularly.

"The dihedral angle of the rhombohedron of calc-spar is 105° 5′*.

"If i be the inclination of the axis to the normal of the plate, we get by a spherical triangle,

$$\sin i = \cos 52^\circ\, 32'{\cdot}5 \operatorname{cosec} 60^\circ$$

whence $i = 44^\circ\, 36'{\cdot}6$.

Now† we have

$$v = \sqrt{a^2 \cos^2 i + c^2 \sin^2 i} = a \cos i \sec \theta$$

where $$\tan \theta = \frac{c}{a} \tan i = \frac{\mu'_o}{\mu'_e} \tan i,$$

and if $$\mu' = \frac{a}{v} \mu'_o \quad \mu' = \mu'_o \sec i \cos \theta.$$

Also $\log \tan i = 9{\cdot}99409$, and $\log \sec i = 10{\cdot}14758$.

Hence $\log \tan \theta = \log \mu'_o - \log \mu'_e + 9{\cdot}99409$

$\log \mu' = \log \mu'_o + \log \cos \theta + 10{\cdot}14758 - 20$.

* PHILLIPS's Mineralogy.

† AIRY's Tract, Art. 151.

"In this manner we obtain the following table:—

(42.) Calc-spar and Oil of Cassia. Extraordinary ray.

Ray.	Calc-spar μ'_O.	Calc-spar μ'_E.	ϑ.	μ'.	Oil of Cassia, μ.	$\mu'-\mu$.	$\frac{\mu'-\mu}{\lambda}$	$\frac{\mu'-\mu}{\lambda}\times\cdot 0$	Diff.
B.	1·6531	1·4839	$47^\circ\ 42'\cdot 0$	1·5628	1·5945	−·0317	−1248	− 49·9	
D.	1·6585	1·4863	44·8	1·5665	1·6073	−·0408	−1876	− 75·0	− 25·1
F.	1·6680	1·4907	49·5	1·5731	1·6358	−·0627	−3495	−139·8	− 64·8
G.	1·6762	1·4945	53·6	1·5787	1·6671	−·0884	−5570	−222·8	− 83·0
H.	1·6833	1·4978	57·0	1·5837	1·7025	−·1188	−8115	−324·6	−101·8
									275

"The direction considered being about 45° from the axis, μ' ought to be nearly equal to the mean of μ'_O μ'_E. Now the values of μ' found above, fall short of the mean of μ'_O and μ'_E by the following quantities:—

For B . . . . . ·0057
D . . . . . ·0059
F . . . . . ·0062
G . . . . . ·0066
H . . . . . ·0068

"The smallness and regularity of these numbers is a test of the correctness of the arithmetic."

(43.) *Quartz and Oil of Sassafras.*

The angle of the prism being 60° and the ray F at the minimum deviation, and φ, φ' being the angles of incidence and refraction for the first surface, we have for either pencil,

$$\varphi'_F = 30^\circ, \quad \sin\varphi_F = \mu_F \sin\varphi'_F,$$

which gives φ_F, and therefore φ for the other rays;

also $$\sin\varphi' = \frac{\sin\varphi}{\mu}$$ gives φ' for the other rays.

If i be the angle of incidence *on the plate* then in position (1) (see figs. 2, 3) $i = 60^\circ - \varphi'$, and in position (2) $i = \varphi'$.

Then (as in AIRY's Tract, Art. 151) if i' be the angle of refraction referring to the *normal of the wave*, we have

$$\tan i' = \frac{a\sin i}{\sqrt{\nu^2 - c^2\sin^2 i}}$$

where $$\frac{a}{c} = \frac{\mu_E}{\mu_O}$$

and $$v' = \sqrt{a^2 \cos^2 i' + c^2 \sin^2 i'},$$

and if V be the velocity in air, so that $\frac{V}{v} = \mu$, and we take $\frac{v'}{v} = \frac{\mu}{\varkappa}$, then $\frac{V}{v'} = \varkappa$;

and M being the retardation expressed by the number of waves' lengths, we get

$$M = \frac{\tau}{\lambda \cos i'} \left(\frac{V}{v'} - \mu \cos (i - i') \right).$$

Also i' is found to differ but little from 30° (about 30′ for the extreme rays) and $\cos (i - i') = \cdot 9999$, which may be put $= 1$. Thus

$$M = \frac{\tau}{\lambda} \sec i' \ (\varkappa - \mu).$$

For the ordinary ray we have simply

$$\sin i' = \frac{\mu}{\mu_o} \sin i$$

and $$M = \frac{\tau}{\lambda} \sec i' (\mu_o - \mu).$$

(44.) In this way the following results are obtained, $\tau = \cdot 15$ inch.

Ray.	Quartz μ_{PO}.	Oil of Sassafras, μ_{ϖ}.	$\mu_P - \mu_{\varpi}$.	$\frac{\mu_P - \mu_{\varpi}}{\lambda}$.	$M' = \left(\frac{\mu_P - \mu_{\varpi}}{\lambda}\right) \tau$.	Position vertical diff. = n.	$M = M' \sec i'$.	Position 1. Diff. = n′.
B.	1·5409	1·5257	+·0152	+598	+ 89·7		+103·4	
D.	1·5441	1·5321	+·0120	+552	+ 82·8	− 7	+ 95·7	− 7
E.	1·5471	1·5387	+·0084	+432	+ 64	− 18	+ 73·9	− 22
F.	1·5496	1·5448	+·0048	+267	+ 40	− 24	+ 46	− 28
G.	1·5542	1·5575	−·0033	−208	− 31	− 71	− 35·8	− 82
H.	1·5582	1·5693	−·0111	−758	−113	− 82	−131	95
						202		234

(45.) For the extraordinary ray Mr. STOKES has made a calculation, of which the following are the principal steps and results. From the expression above,

$$v' = a \cos i' \sqrt{1 + \frac{c^2}{a^2} \tan^2 i'};$$

and assuming $$\tan \theta = \frac{c}{a} \tan i' = \frac{\mu_o}{\mu_e} \tan i',$$

whence $$v' = a \cos i' \sec \theta,$$

$$\varkappa = \frac{V}{v'} = \mu_o \sec i' \cos \theta.$$

(46.) To obtain $\varkappa$, assuming i' approximately as differing little from i, which is near enough for this purpose, the following values result :—

Ray.	μ_B.	μ_R.	$\varkappa$.		μ.	$\sin\phi=\mu\sin\phi'$.	Pos. 1. $i=60-\phi'$.	Pos. 2. $i=\phi$.
			Pos. (1).	Pos. (2).	Sassafras.	ϕ'.		
B.	1·5409	1·5499	1·5430	1·5432	1·52575	30° 25′ 0″	29° 35′ 0″	30° 25′ 0″
D.	1·5442	1·5533	1·5464	1·5465	1·53215	30 16 30	29 43 30	30 16 30
E.	1·5471	1·5563	1·5494	1·5494	1·53870	30 30 80	29 52 0	30 30 80
F.	1·5496	1·5589	1·5519	1·5519	1·54485	30 0 0	30 0 0	30 0 0
G.	1·5542	1·5636	1·5566	1·5565	1·55750	29 44 0	30 16 0	29 44 0
H.	1·5582	1·5677	1·5607	1·5605	1·56935	29 29 0	30 31 0	29 29 0

(47.) Then with more accurate values of i' we obtain, successively,

Ray.	$\sin i'=\frac{\mu}{\varkappa}\sin i$. i'.		$\varkappa-\mu$.		$\frac{\varkappa-\mu}{\lambda\cos i'}$.		$\left(\frac{\varkappa-\mu}{\lambda\cos i'}\right)\tau=\mathrm{M}$.		Diff. $=n'$.	
	Position 1.	Position 2.	Pos. 1.	Pos. 2.	Pos. 1.	Pos. 2.	Pos. 1.	Pos. 2.	Pos. 1.	Pos. 2.
B.	29° 13′ 0″	30° 2′ 0″	+·0173	+·0175	+779	+795	+117	+119		
D.	29 25 30	29 58 0	+·0143	+·0144	+754	+762	+113	+114	− 4	− 5
E.	29 38 30	29 54	+·0107	+·0107	+633	+634	+ 95	+ 95	−18	−19
F.	29 51	29 51	+·0071	+·0071	+451	+451	+ 68	+ 68	−27	−27
G.	30 17	29 45	−·0009	−·0010	− 65	− 73	− 10	− 11	−78	−79
H.	30 42	29 40	−·0086	−·0088	−683	−694	−102	−104	−92	−93
									219	223

Hence arrangement I. gives bands.

(48.) For the ordinary ray with the plate vertical, the number of bands agrees well with observation as far as it goes.

It is obvious in general, that if two sets of bands differing in number be superposed, there will be a number of coincidences equal to their difference, separated by spaces of partial obliteration, which if the bands be of sensible breadth, will extend over several bands.

On comparing the above values of p for O and for E in position 1, we find—

From B to E . . . 29 − 22 = 7
From E to H . . . 205 − 197 = 8
From B to H . . . . . = 15
} = number of intervals of indistinctness.

From E to H this agrees with observation, and may do so from B to E, occasioning a total disappearance of bands.

Postscript.—At the time the foregoing paper was communicated to the Royal Society, I had not seen Mr. Stokes's paper; nor in writing his, had he seen mine at length; hence it will be found that there are some repetitions in the latter, of points mentioned in mine, but usually put in so much clearer a light that the reader will not regret the repetition.

XVI. *On the Theory of certain Bands seen in the Spectrum.*

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Communicated by the Rev. Baden Powell, *M.A., F.R.S., &c.*

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SOME months ago Professor Powell communicated to me an account of a new case of interference which he had discovered in the course of some experiments on a fluid prism, requesting at the same time my consideration of the theory. As the phenomenon is fully described in Professor Powell's memoir, and is briefly noticed in art. 1 of this paper, it is unnecessary here to allude to it. It struck me that the theory of the phenomenon was almost identical with that of the bands seen when a spectrum is viewed by an eye, half the pupil of which is covered by a plate of glass or mica. The latter phenomenon has formed the subject of numerous experiments by Sir David Brewster, who has discovered a very remarkable polarity, or apparent polarity, in the bands. The theory of these bands has been considered by the Astronomer Royal in two memoirs "On the Theoretical Explanation of an apparent new Polarity of Light," printed in the Philosophical Transactions for 1840 (Part II.) and 1841 (Part I.). In the latter of these Mr. Airy has considered the case in which the spectrum is viewed in focus, which is the most interesting case, as being that in which the bands are best seen, and which is likewise far simpler than the case in which the spectrum is viewed out of focus. Indeed, from the mode of approximation adopted, the former memoir can hardly be considered to belong to the bands which formed the subject of Sir David Brewster's experiments, although the memoir no doubt contains the theory of a possible system of bands. On going over the theory of the bands seen when the spectrum is viewed in focus, after the receipt of Professor Powell's letter, I was led to perceive that the intensity of the light could be expressed in finite terms. This saves the trouble of Mr. Airy's quadratures, and allows the results to be discussed with great facility. The law, too, of the variation of the intensity with the thickness of the plate is very remarkable, on account of its discontinuity. These reasons have induced me to lay my investigation before the Royal Society, even though the remarkable polarity of the bands has been already explained by the Astronomer Royal. The observation of these bands seems likely to become of great importance in the determination of the refractive indices, and more especially the laws of dispersion, of minerals and other substances which cannot be formed into prisms which would exhibit the fixed lines of the spectrum.

SECTION I.—*Explanation of the formation of the bands on the imperfect theory of Interferences. Mode of calculating the number of bands seen in a given part of the spectrum.*

1. The phenomenon of which it is the principal object of the following paper to investigate the theory, is briefly as follows. Light introduced into a room through a horizontal slit is allowed to pass through a hollow glass prism containing fluid, with its refracting edge horizontal, and the spectrum is viewed through a small telescope with its object-glass close to the prism. On inserting into the fluid a transparent plate with its lower edge horizontal, the spectrum is seen traversed from end to end by very numerous dark bands, which are parallel to the fixed lines. Under favorable circumstances the dark bands are intensely black; but in certain cases, to be considered presently, no bands whatsoever are seen. When the plate is cut from a doubly refracting crystal, there are in general two systems of bands seen together; and when the light is analysed each system disappears in turn at every quarter revolution of the analyser.

2. It is not difficult to see that the theory of these bands must be almost identical with that of the bands described by Sir DAVID BREWSTER in the Report of the Seventh Meeting of the British Association, and elsewhere, and explained by Mr. AIRY in the first Part of the Philosophical Transactions for 1841. To make this apparent, conceive an eye to view a spectrum through a small glass vessel with parallel faces filled with fluid. The vessel would not alter the appearance of the spectrum. Now conceive a transparent plate bounded by parallel surfaces inserted into the fluid, the plane of the plate being perpendicular to the axis of the eye, and its edge parallel to the fixed lines of the spectrum, and opposite to the centre of the pupil. Then we should have bands of the same nature as those described by Sir DAVID BREWSTER, the only difference being that in the present case the retardation on which the existence of the bands depends is the difference of the retardations due to the plate itself, and to a plate of equal thickness of the fluid, instead of the absolute retardation of the plate, or more strictly, the difference of retardations of the solid plate and of a plate of equal thickness of air, contained between the produced parts of the bounding planes of the solid plate. In Professor POWELL's experiment the fluid fills the double office of the fluid in the glass vessel and of the prism producing the spectrum in the imaginary experiment just described.

It might be expected that the remarkable polarity discovered by Sir DAVID BREWSTER in the bands which he has described, would also be exhibited with Professor POWELL's apparatus. This anticipation is confirmed by experiment. With the arrangement of the apparatus already mentioned, it was found that with certain pairs of media, one being the fluid and the other the retarding plate, no bands were visible. These media were made to exhibit bands by using fluid enough to cover the plate to a certain depth, and stopping by a screen the light which would otherwise have passed through the thin end of the prism underneath the plate.

3. Although the explanation of the polarity of the bands depends on diffraction, it may be well to account for their formation on the imperfect theory of interferences, in which it is supposed that light consists of rays which follow the courses assigned to them by geometrical optics. It will thus readily appear that the number of bands formed with a given plate and fluid, and in a given part of the spectrum, has nothing to do with the form or magnitude of the aperture, whatever it be, which limits the pencil that ultimately falls on the retina. Moreover, it seems desirable to exhibit in its simplest shape the mode of calculating the number of bands seen in any given case, more especially as these calculations seem likely to be of importance in the determination of refractive indices.

4. Before the insertion of the plate, the wave of light belonging to a particular colour, and to a particular point of the slit, or at least a certain portion of it limited by the boundaries of the fluid, after being refracted at the two surfaces of the prism, enters the object-glass with an unbroken front. The front is here called unbroken, because the modification which the wave suffers at its edges is not contemplated. According to geometrical optics, the light after entering the object-glass is brought to a point near the principal focus, spherical aberration being neglected; according to the undulatory theory, it forms a small, but slightly diffused image of the point from which it came. The succession of these images due to the several points of the slit forms the image of the slit for the colour considered, and the succession of coloured images forms the spectrum, the waves for the different colours covering almost exactly the same portion of the object-glass, but differing from one another in direction.

Apart from all theory, it is certain that the image of a point or line of homogeneous light seen with a small aperture is diffused. As the aperture is gradually widened the extent of diffusion decreases continuously, and at last becomes insensible. The perfect continuity, however, of the phenomenon shows that the true and complete explanation, whatever it may be, of the narrow image seen with a broad aperture, ought also to explain the diffused image seen with a narrow aperture. The undulatory theory explains perfectly both the one and the other, and even predicts the distribution of the illumination in the image seen with an aperture of given form, which is what no other theory has ever attempted.

As an instance of the effect of diffusion in an image, may be mentioned the observed fact that the definition of a telescope is impaired by contracting the aperture. With a moderate aperture, however, the diffusion is so slight as not to prevent fine objects, such as the fixed lines of the spectrum, from being well seen.

For the present, however, let us suppose the light entering the telescope to consist of rays which are brought accurately to a focus, but which nevertheless interfere. When the plate is inserted into the fluid the front of a wave entering the object-glass will no longer be unbroken, but will present as it were a *fault*, in consequence of the retardation produced by the plate. Let R be this retardation measured by

actual length in air, ϱ the retardation measured by phase, M the retardation measured by the number of waves' lengths, so that

$$\varrho=\frac{2\pi}{\lambda}\mathrm{R},\ \mathrm{M}=\frac{1}{\lambda}\mathrm{R};$$

then when M is an odd multiple of $\frac{1}{2}$, the vibrations produced by the two streams, when brought to the same focus, will oppose each other, and there will be a minimum of illumination; but when M is an even multiple of $\frac{1}{2}$ the two streams will combine, and the illumination will be a maximum. Now M changes in passing from one colour to another in consequence of the variations both of R and of λ; and since the different colours occupy different angular positions in the field of view, the spectrum will be seen traversed by dark and bright bands. It is nearly thus that Mr. Talbot has explained the bands seen when a spectrum is viewed through a hole in a card which is half-covered with a plate of glass or mica, with its edge parallel to the fixed lines of the spectrum. Mr. Talbot however does not appear to have noticed the polarity of the bands.

Let h, k be the breadths of the interfering streams; then we may take

$$h\sin\frac{2\pi}{\lambda}vt,\ k\sin\left(\frac{2\pi}{\lambda}vt-\varrho\right)$$

to represent the vibrations produced at the focus by the two streams respectively, which gives for the intensity I,

$$\mathrm{I}=(h+k\cos\varrho)^2+(k\sin\varrho)^2=h^2+k^2+2hk\cos\varrho, \quad \ldots\ldots \quad (1.)$$

which varies between the limits $(h-k)^2$ and $(h+k)^2$.

5. Although the preceding explanation is imperfect, for the reason already mentioned, and does not account for the polarity, it is evident that if bands are formed at all in this way, the number seen in a given part of the spectrum will be determined correctly by the imperfect theory; for everything will recur, so far as interference is concerned, when M is decreased or increased by 1, and not before. This points out an easy mode of determining the number of bands seen in a given part of the spectrum. For the sake of avoiding a multiplicity of cases, let an acceleration be reckoned as a negative retardation, and suppose R positive when the stream which passes nearer to the edge of the prism is retarded relatively to the other. From the known refractive indices of the plate and fluid, and from the circumstances of the experiment, calculate the values of R for each of the fixed lines B, C . . . . H of the spectrum, or for any of them that may be selected, and thence the values of M, by dividing by the known values of λ. Set down the results with their proper signs opposite to the letters B, C . . . denoting the rays to which they respectively refer, and then form a table of differences by subtracting the value of M for B from the value for C, the value for C from the value for D, and so on. Let N be the number found in the table of differences corresponding to any interval, as for example from F to G; then the numerical value of N, that is to say, N or $-$N, according as N is positive

or negative, gives the number of bands seen between F and G. For anything that appears from the imperfect theory of the bands given in the preceding article, it would seem that the sign of N was of no consequence. It will presently be seen, however, that the sign is of great importance: it will be found in fact that the sign + indicates that the second arrangement mentioned in art. 2 must be employed; that is to say, the plate must be made to intercept light from the thin end of the prism, while the sign − indicates that the first arrangement is required. It is hardly necessary to remark that, if N should be fractional, we must, instead of the number of bands, speak of the number of band-intervals and the fraction of an interval.

Although the number of bands depends on nothing but the values of N, the values of M are not without physical interest. For M expresses, as we have seen, the number of waves' lengths whereby one of the interfering streams is before or behind the other. Mr. AIRY speaks of the formation of rings with the light of a spirit-lamp when the retardation of one of the interfering streams is as much as fifty or sixty waves' lengths. But in some of Professor POWELL's experiments, bands were seen which must have been produced by retardations of several hundred waves' lengths. This exalts our ideas of the regularity which must be attributed to the undulations.

6. It appears then that the calculation of the number of bands is reduced to that of the retardation R. As the calculation of R is frequently required in physical optics, it will not be necessary to enter into much detail on this point. The mode of performing the calculation, according to the circumstances of the experiment, will best be explained by a few examples.

Suppose the retarding plate to belong to an ordinary medium, and to be placed so as to intercept light from the thin end of the prism, and to have its plane equally inclined to the faces of the prism. Suppose the prism turned till one of the fixed lines, as F, is seen at a minimum deviation; then the colours about F are incident perpendicularly on the plate; and all the colours may without material error be supposed to be incident perpendicularly, since the directions of the different colours are only separated by the dispersion accompanying the first refraction into the fluid, and near the normal a small change in the angle of incidence produces only a very small change in the retardation. The dispersion accompanying the first refraction into the fluid has been spoken of as if the light were refracted from air directly into the fluid, which is allowable, since the glass sides of the hollow prism, being bounded by parallel surfaces, may be dispensed with in the explanation. Let T be the thickness of the plate, μ the refractive index of the fluid, μ' that of the plate; then

$$R=(\mu'-\mu)T. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

If the plate had been placed so as to intercept light from the thick end of the prism, we should have had $-R=(\mu'-\mu)T$, which would have agreed with (2.) if we had supposed T negative. For the future T will be reckoned positive when the plate intercepts light from the thin end of the prism, and negative when it intercepts light

from the thick end, so that the same formulæ will apply to both of the arrangements mentioned in art. 2.

If we put $\mu=1$, the formula (2.) will apply to the experiment in which a plate of glass or mica is held so as to cover half the pupil of the eye when viewing a spectrum formed in any manner, the plate being held perpendicularly to the axis of the eye. The effect of the small obliquity of incidence of some of the colours is supposed to be neglected.

The number of bands which would be determined by means of the formula (2.) would not be absolutely exact, unless we suppose the observation taken by receiving each fixed line in succession at a perpendicular incidence. This may be effected in the following manner. Suppose that we want to count the number of bands between F and G, move the plate by turning it round a horizontal axis till the bands about F are seen stationary; then begin to count from F, and before stopping at G incline the plate a little till the bands about G are seen stationary, estimating the fractions of an interval at F and G, if the bands are not too close. The result will be strictly the number given by the formula (2.). The difference, however, between this result and that which would be obtained by keeping the plate fixed would be barely sensible. If the latter mode of observation should be thought easier or more accurate, the exact formula which would replace (2.) would be easily obtained.

7. Suppose now the nearer face of the retarding plate made to rest on the nearer inner face of the hollow prism, and suppose one of the fixed lines, as F, to be viewed at a minimum deviation. Let ϕ, ϕ' be the angles of incidence and refraction at the first surface of the fluid, i, i' those at the surface of the plate, 2ε the angle of the prism. Since the deviation of F is a minimum, the angle of refraction ϕ'_{F} for F is equal to ε, and the angle of incidence ϕ is given by $\sin\phi=\mu_{\mathrm{F}}\sin\phi'_{\mathrm{F}}$, and ϕ is the angle of incidence for all the colours, the incident light being supposed white. The angle of refraction ϕ' for any fixed line is given by the equation $\sin\phi'=\frac{1}{\mu}\sin\phi=\frac{\mu_{\mathrm{F}}}{\mu}\sin\varepsilon$; then $i=2\varepsilon-\phi'$, and i' is known from the equation

$$\mu'\sin i'=\mu\sin i. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

The retardation is given by either of the formulæ

$$\mathrm{R}=\mu''\mathrm{T}\frac{\sin(i-i')}{\sin i}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

$$\mathrm{R}=\mathrm{T}(\mu'\cos i'-\mu\cos i). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

These formulæ might be deduced from that given in Airy's Tract, modified so as to suit the case in which the plate is immersed in a fluid; but either of them may be immediately proved independently by referring everything to the wave's front and not the ray.

By multiplying and dividing the second side of (5.) by $\cos i$, and employing (3.), we get

$$\mathrm{R}=\mathrm{T}\sec i\,.(\mu'-\mu)-\mathrm{T}\mu'\sec i\,\mathrm{versin}\,(i-i'). \quad . \quad . \quad . \quad . \quad . \quad (6.)$$

When the refractive indices of the plate and fluid are nearly equal, the last term in this equation may be considered insensible, so that it is not necessary to calculate i' at all.

8. The formulæ (2.), (4.), (5.), (6.) are of course applicable to the ordinary ray of a plate cut from a uniaxal crystal. If the plate be cut in a direction parallel to the axis, and if moreover the lower edge be parallel to the axis, so that the axis is parallel to the refracting edge of the prism, the formulæ will apply to both rays. If μ_o, μ_e be the principal indices of refraction referring to the ordinary and extraordinary rays respectively, μ' in the case last supposed must be replaced by μ_o for the bands polarized in a plane perpendicular to the plane of incidence, and by μ_e for the bands polarized in the plane of incidence. In the case of a plate cut from a biaxal crystal in such a direction that one of the principal axes, or axes of elasticity, is parallel to the refracting edge, the same formulæ will apply to that system of bands which is polarized in the plane of incidence.

If the plate be cut from a biaxal crystal in a direction perpendicular to one of the principal axes, and be held in the vertical position, the formula (2.) will apply to both systems of bands, if the small effect of the obliquity be neglected. The formula would be exact if the observations were taken by receiving each fixed line in succession at a perpendicular incidence.

If the plate be cut from a uniaxal crystal in a direction perpendicular to the axis, and be held obliquely, we have for the extraordinary bands, which are polarized in a plane perpendicular to the plane of incidence,

$$R=T\left(\frac{\mu_o}{\mu_e}\sqrt{\mu_e^2-\mu^2\sin^2 i}-\mu\cos i\right), \quad \ldots\ldots\ldots \quad (7.)$$

which is the same as the formula in AIRY's Tract, only modified so as to suit the case in which the plate is immersed in fluid, and expressed in terms of refractive indices instead of velocities. If we take a subsidiary angle j, determined by the equation

$$\sin j=\frac{\mu}{\mu_e}\sin i, \quad \ldots\ldots\ldots\ldots \quad (8.)$$

the formula (7.) becomes

$$R=T(\mu_o\cos j-\mu\cos i), \quad \ldots\ldots\ldots\ldots \quad (9.)$$

which is of the same form as (5.), and may be adapted to logarithmic calculation if required by assuming $\frac{\mu_o}{\mu}=\tan\theta$. The preceding formula will apply to the extraordinary bands formed by a plate cut from a biaxal crystal in the manner described in the last paragraph, and held obliquely, the extraordinary bands being understood to mean those which are polarized in a plane perpendicular to the plane of incidence. In this application we must take for μ_e, μ_o those two of the three principal indices of refraction which are symmetrically related to the axis normal to the plate, and to the axis parallel to the plate, and lying in the plane of incidence, respectively; while

in applying the formula (4.), (5.) or (6.) to the other system of bands, the third principal index must be substituted for μ'.

It is hardly necessary to consider the formula which would apply to the general case, which would be rather complicated.

9. If a plate cut from a uniaxal crystal in a direction perpendicular to the axis be placed in the fluid in an inclined position, and be then gradually made to approach the vertical position, the breadths of the bands belonging to the two systems will become more and more nearly equal, and the two systems will at last coalesce. This statement indeed is not absolutely exact, because the whole spectrum cannot be viewed at once by light which passes along the axis of the crystal, on account of the dispersion accompanying the first refraction, but it is very nearly exact. With quartz it is true there would be two systems of bands seen even in the vertical position, on account of the peculiar optical properties of that substance; but the breadths of the bands belonging to the two systems would be so nearly equal, that it would require a plate of about one-fifth of an inch thickness to give a difference of one in the number of bands seen in the whole spectrum in the case of the two systems respectively. If the plate should be thick enough to exhibit both systems, the light would of course have to be circularly analysed to show one system by itself.

SECTION II.—*Investigation of the intensity of the light on the complete theory of undulations, including the explanation of the apparent polarity of the bands.*

10. The explanation of the formation of the bands on the imperfect theory of interferences considered in the preceding section is essentially defective in this respect, that it supposes an annihilation of light when two interfering streams are in opposition; whereas it is a most important principle that *light is never lost by interference*. This statement may require a little explanation, without which it might seem to contradict received ideas. It is usual in fact to speak of light as *destroyed* by interference. Although this is true, in the sense intended, the expression is perhaps not very happily chosen. Suppose a portion of light coming from a luminous point, and passing through a moderately small aperture, to be allowed to fall on a screen. We know that there would be no sensible illumination on the screen except almost immediately in front of the aperture. Conceive now the aperture divided into a great number of small elements, and suppose the same quantity of light as before to pass through each element, the only difference being that now the vibrations in the portions passing through the several elements are supposed to have no relation to each other. The light would now be diffused over a comparatively large portion of the screen, so that a point P which was formerly in darkness might now be strongly illuminated. The disturbance at P is in both cases the aggregate of the disturbances due to the several elements of the aperture; but in the first case the aggregate is insensible on account of interference. It is only in this sense that light is *destroyed* by interference, for the total illumination on the screen is the same in the two cases;

the effect of interference has been, not to annihilate any light, but only to alter the "distribution of the illumination," so that the light, instead of being diffused over the screen, is concentrated in front of the aperture.

Now in the case of the bands considered in Section I., if we suppose the plate extremely thin, the bands will be very broad; and the displacement of illumination due to the retardation being small compared with the breadth of a band, it is evident, without calculation, that at most only faint bands can be formed. This particular example is sufficient to show the inadequacy of the imperfect theory, and the necessity of an exact investigation.

11. Suppose first that a point of homogeneous light is viewed through a telescope. Suppose the object-glass limited by a screen in which there is formed a rectangular aperture of length $2l$. Suppose a portion of the incident light retarded, by passing through a plate bounded by parallel surfaces, and having its edge parallel to the length of the aperture. Suppose the unretarded stream to occupy a breadth h of the aperture at one side, the retarded stream to occupy a breadth k at the other, while an interval of breadth $2g$ exists between the streams. In the apparatus mentioned in Section I., the object-glass is not limited by a screen, but the interfering streams of light are limited by the dimensions of the fluid prism, which comes to the same thing. The object of supposing an interval to exist between the interfering streams, is to examine the effect of the gap which exists between the streams when the retarding plate is inclined. In the investigation the effect of diffraction before the light reaches the object-glass of the telescope is neglected.

Let O be the image of the luminous point, as determined by geometrical optics, f the focal length of the object-glass, or rather the distance of O from the object-glass, which will be a little greater than the focal length when the luminous point is not very distant. Let C be a point in the object-glass, situated in the middle of the interval between the two streams, and let the intensity be required at a point M, near O, situated in a plane passing through O and perpendicular to OC. The intensity at any point of this plane will of course be sensibly the same as if the plane were drawn perpendicular to the axis of the telescope instead of being perpendicular to OC. Take OC for the axis of z, the axes of x and y being situated in the plane just mentioned, and that of y being parallel to the length of the aperture. Let p, q be the coordinates of M; x, y, z those of a point P in the front of a wave which has just passed through the object-glass, and which forms part of a sphere with O for its centre. Let c be the coefficient of vibration at the distance of the object-glass; then we may take

$$\frac{c}{\lambda}\frac{1}{\mathrm{PM}}\sin\frac{2\pi}{\lambda}(vt-\mathrm{PM})\,dxdy \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a.)$$

to represent the disturbance at M due to the element $dxdy$ of the aperture at P, P being supposed to be situated in the unretarded stream, which will be supposed to lie at the negative side of the axis of x. In the expression (a.) it is assumed that the

proper multiplier of $\frac{c}{\mathrm{PM}}$ is $\frac{1}{\lambda}$. This may be shown to be a necessary consequence of the principle mentioned in the preceding article, that light is never lost by interference; and this principle follows directly from the principle of *vis viva*. In proving that λ^{-1} is the proper multiplier, it is not in the least necessary to enter into the consideration of the law of the variation of intensity in a secondary wave, as the angular distance from the normal to the primary wave varies; the result depends merely on the assumption that in the immediate neighbourhood of the normal the intensity may be regarded as sensibly constant.

In the expression (*a*.) we have

$$\mathrm{PM}=\surd\{z^2+(x-p)^2+(y-q)^2\}=\surd\{f^2+p^2+q^2-2px-2qy\}=f-\frac{1}{f}(px+qy),\text{ nearly,}$$

if we write f for $\sqrt{f^2+p^2+q^2}$. It will be sufficient to replace $\frac{1}{\mathrm{PM}}$ outside the circular function by $\frac{1}{f}$. We may omit the constant f under the circular function, which comes to the same thing as changing the origin of t. We thus get for the disturbance at M due to the unretarded stream,

$$\frac{c}{\lambda f}\int_{-(g+k)}^{-g}\int_{-l}^{l}\sin\frac{2\pi}{\lambda}\{vt+\frac{1}{f}(px+qy)\}\,dx\,dy,$$

or on performing the integrations and reducing,

$$\frac{2ckl}{\lambda f}\cdot\frac{\lambda f}{2\pi ql}\sin\frac{2\pi ql}{\lambda f}\cdot\frac{\lambda f}{\pi pk}\sin\frac{\pi pk}{\lambda f}\cdot\sin\frac{2\pi}{\lambda}\Big(vt-\frac{pg}{f}-\frac{pk}{2f}\Big).\quad\ldots\quad(b.)$$

For the retarded stream, the only difference is that we must subtract R from vt, and that the limits of x are g and $g+k$. We thus get for the disturbance at M due to this stream,

$$\frac{2ckl}{\lambda f}\cdot\frac{\lambda f}{2\pi ql}\sin\frac{2\pi ql}{\lambda f}\cdot\frac{\lambda f}{\pi pk}\sin\frac{\pi pk}{\lambda f}\cdot\sin\frac{2\pi}{\lambda}\Big(vt-\mathrm{R}+\frac{pg}{f}+\frac{pk}{2f}\Big).\quad\ldots\quad(c.)$$

If we put for shortness τ for the quantity under the last circular function in (*b*.), the expressions (*b*.), (*c*.) may be put under the forms $u\sin\tau, v\sin(\tau-\alpha)$, respectively; and if I be the intensity, I will be measured by the sum of the squares of the coefficients of $\sin\tau$ and $\cos\tau$ in the expression

$$u\sin\tau+v\sin(\tau-\alpha),$$

so that

$$\mathrm{I}=u^2+v^2+2uv\cos\alpha,$$

which becomes, on putting for u, v and α, their values, and putting

$$\Big\{\frac{\lambda f}{2\pi ql}\sin\frac{2\pi ql}{\lambda f}\Big\}^2=\mathrm{Q},\quad\ldots\quad(10.)$$

$$\mathrm{I}=\mathrm{Q}\cdot\frac{4c^2l^2}{\pi^2p^2}\Big\{\Big(\sin\frac{\pi ph}{\lambda f}\Big)^2+\Big(\sin\frac{\pi pk}{\lambda f}\Big)^2+2\sin\frac{\pi ph}{\lambda f}\cdot\sin\frac{\pi pk}{\lambda f}\cos\Big[\varrho-\frac{\pi p}{\lambda f}(4g+h+k)\Big]\Big\}.\quad(11.)$$

12. Suppose now that instead of a point we have a line of homogeneous light, the

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line being parallel to the axis of y. The luminous line is supposed to be a narrow slit, through which light enters in all directions, and which is viewed in focus. Consequently each element of the line must be regarded as an independent source of light. Hence the illumination on the object-glass due to a portion of the line which subtends the small angle β at the distance of the object-glass varies as β, and may be represented by $A\beta$. Let the former origin O be referred to a new origin O′ situated in the plane xy, and in the image of the line; and let η, q' be the ordinates of O, M referred to O′, so that $q=q'-\eta$. In order that the luminous point considered in the last article may represent an element of the luminous line considered in the present, we must replace c^2 by $Ad\beta$ or $\frac{A}{f}d\eta$; and in order to get the aggregate illumination due to the whole line, we must integrate from a large negative to a large positive value of η, the largeness being estimated by comparison with $\frac{\lambda f}{l}$. Now the angle $\frac{2\pi ql}{\lambda f}$ changes by π when q changes by $\frac{\lambda f}{2l}$, which is therefore the breadth, in the direction of y, of one of the diffraction bands which would be seen with a luminous point. Since l is supposed not to be extremely small, but on the contrary moderately large, the whole system of diffraction bands would occupy but a very small portion of the field of view in the direction of y, so that we may without sensible error suppose the limits of η to be $-\infty$ and $+\infty$. We have then

$$\int_{-\infty}^{\infty} Q d\eta = \int_{-\infty}^{\infty} \left\{ \frac{\lambda f}{2\pi l(q'-\eta)} \sin \frac{2\pi l(q'-\eta)}{\lambda f} \right\}^2 d\eta = \frac{\lambda f}{2\pi l} \int_{-\infty}^{\infty} \left(\frac{\sin \theta}{\theta} \right)^2 d\theta,$$

by taking the quantity under the circular function in place of η for the independent variable. Now it is known that the value of the last integral is π, as will also presently appear, and therefore we have for the intensity I at any point,

$$I = \frac{2A\lambda l}{\pi^2 p^2} \left\{ \left(\sin \frac{\pi ph}{\lambda f} \right)^2 + \left(\sin \frac{\pi pk}{\lambda f} \right)^2 + 2 \sin \frac{\pi ph}{\lambda f} \cdot \sin \frac{\pi pk}{\lambda f} \cdot \cos \left[\xi - \frac{\pi p}{\lambda f} (4g+h+k) \right] \right\}, \quad (12.)$$

which is independent of q', as of course it ought to be.

13. Suppose now that instead of a line of homogeneous light we have a line of white light, the component parts of which have been separated, whether by refraction or by diffraction is immaterial, so that the different colours occupy different angular positions in the field of view. Let $B\beta\psi$ be the illumination on the object-glass due to a length of the line which subtends the small angle β, and to a portion of the spectrum which subtends the small angle ψ at the centre of the object-glass. In the axis of x take a new origin O″, and let ξ, p' be the abscissæ of O′, M reckoned from O″, so that $p=p'-\xi$. In order that (12.) may express the intensity at M due to an elementary portion of the spectrum, we must replace A by $Bd\psi$, or $\frac{B}{f}d\xi$; and in order to find the aggregate illumination at M, we must integrate so as to include all values of ξ which are sufficiently near to p' to contribute sensibly to the illumination

at M. It would not have been correct to integrate using the displacement instead of the intensity, because the different colours cannot interfere. Suppose the angular extent, in the direction of x, of the system of diffraction bands which would be seen with homogeneous light, or at least the angular extent of the brighter part of the system, to be small compared with that of the spectrum. Then we may neglect the variations of B and of λ in the integration, considering only those of ξ and ϱ, and we may suppose the changes of ϱ proportional to those of ξ; and we may moreover suppose the limits of ξ to be $-\infty$ and $+\infty$. Let ϱ' be the value of ϱ, and $-\varpi$ that of $\frac{d\varrho}{d\xi}$, when $\xi=p'$, so that we may put $\varrho=\varrho'+\varpi(p'-\xi)$; and take p instead of ξ for the independent variable. Then putting for shortness

$$\frac{\pi h}{\lambda f}=h_i, \qquad \frac{\pi k}{\lambda f}=k_i, \qquad \varpi-\frac{\pi}{\lambda f}(4g+h+k)=g_i, \quad . \quad . \quad . \quad . \quad . \quad (13.)$$

we have for the intensity,

$$\mathrm{I}=\frac{2\mathrm{B}\lambda l}{\pi^2 f}\int_{-\infty}^{\infty}\{\sin^2 h_i p+\sin^2 k_i p+2\sin h_i p\,.\sin k_i p\,.\cos(\varrho'-g_i p)\}\frac{dp}{p^2}.$$

Now $\int_{-\infty}^{\infty}\sin^2 h_i p\,\frac{dp}{p^2}=h_i\int_{-\infty}^{\infty}\sin^2\theta\,\frac{d\theta}{\theta^2}=\pi h_i$. Similarly, $\int_{-\infty}^{\infty}\sin^2 k_i p\,.\,\frac{dp}{p^2}=\pi k_i$.

Moreover, if we replace

$$\cos(\varrho'-g_i p) \text{ by } \cos\varrho'\,.\cos g_i p+\sin\varrho'\,.\sin g_i p,$$

the integral containing $\sin\varrho'$ will disappear, because the positive and negative elements will destroy each other, and we have only to find w, where

$$w=\int_{-\infty}^{\infty}\sin h_i p\,.\sin k_i p\,.\cos g_i p\,.\frac{dp}{p^2}.$$

Now we get by differentiating under the integral sign,

$$\frac{dw}{dg_i}=-\int_{-\infty}^{\infty}\sin h_i p\,.\sin k_i p\,.\sin g_i p\,.\frac{dp}{p}$$

$$=\frac{1}{4}\int_{-\infty}^{\infty}\Big\{\sin(g_i+h_i+k_i)p+\sin(g_i-h_i-k_i)p-\sin(g_i+h_i-k_i)p-\sin(g_i+k_i-h_i)p\Big\}\frac{dp}{p}.$$

But it is well known that

$$\int_{-\infty}^{\infty}\frac{\sin sp}{p}\,dp=\pi, \text{ or } =-\pi,$$

according as s is positive or negative. If then we use $\mathrm{F}(s)$ to denote a discontinuous function of s which is equal to $+1$ or -1 according as s is positive or negative, we get

$$\frac{dw}{dg_i}=\frac{\pi}{4}\Big\{\mathrm{F}(g_i+h_i+k_i)+\mathrm{F}(g_i-h_i-k_i)-\mathrm{F}(g_i+h_i-k_i)-\mathrm{F}(g_i+k_i-h_i)\Big\}.$$

This equation gives

$$\frac{dw}{dg_i}=0, \text{ from } g_i=-\infty \text{ to } g_i=-(h_i+k_i)$$

$=\frac{\pi}{2}$, from $g_i=-(h_i+k_i)$ to $g_i=-(h_i\sim k_i)$

$=0$, from $g_i=-(h_i\sim k_i)$ to $g_i=+(h_i\sim k_i)$

$=-\frac{\pi}{2}$, from $g_i=h_i\sim k_i$ to $g_i=h_i+k_i$

$=0$, from $g_i=h_i+k_i$ to $g_i=\infty$.

Now w vanishes when g_i is infinite, on account of the fluctuation of the factor $\cos g_i p$ under the integral sign, whence we get by integrating the value of $\frac{dw}{dg_i}$ given above, and correcting the integral so as to vanish for $g_i=-\infty$,

$w=0$, from $g_i=-\infty$ to $g_i=-(h_i+k_i)$;

$w=\frac{\pi}{2}(h_i+k_i+g_i)$, from $g_i=-(h_i+k_i)$ to $g_i=-(h_i\sim k_i)$;

$w=\pi k_i$ or $=\pi h_i$, (according as $h_i>k_i$ or $h_i<k_i$) from $g=-(h_i\sim k_i)$ to $g_i=+(h_i\sim k_i)$;

$w=\frac{\pi}{2}(h_i+k_i-g_i)$, from $g_i=h_i\sim k_i$ to $g_i=h_i+k_i$;

$w=0$, from $g_i=h_i+k_i$ to $g_i=\infty$.

Substituting in the expression for the intensity, and putting $g_i=\frac{\pi g'}{\lambda f}$, so that

$$g'=\frac{\varpi\lambda f}{\pi}-4g-h-k, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14.)$$

we get

$$\mathrm{I}=\frac{2\mathrm{B}l}{f^2}(h+k), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15.)$$

when the numerical value of g' exceeds $h+k$;

$$\mathrm{I}=\frac{2\mathrm{B}l}{f^2}\left\{h+k+(h+k-\sqrt{g'^2})\cos\xi'\right\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16.)$$

when the numerical value of g' lies between $h+k$ and $h\sim k$;

$$\mathrm{I}=\frac{2\mathrm{B}l}{f^2}(h+k+2h\cos\xi'), \text{ or } =\frac{2\mathrm{B}l}{f^2}(h+k+2k\cos\xi'), \quad . \quad . \quad . \quad . \quad (17.)$$

according as h or k is the smaller of the two, when the numerical value of g' is less than $h\sim k$.

The discontinuity of the law of intensity is very remarkable.

By supposing $g_i=0$, $k_i=h_i$ in the expression for w, and observing that these suppositions reduce w to $\int_{-\infty}^{\infty}\sin^2 h_i p\,.\frac{dp}{p^2}$ we get

$$\int_{-\infty}^{\infty}\left(\frac{\sin h_i p}{p}\right)^2 dp=\pi h_i,$$

a result already employed. This result would of course have been obtained more readily by differentiating with respect to h_i.

14. The preceding investigation will apply, with a very trifling modification, to Sir DAVID BREWSTER's experiment, in which the retarding plate, instead of being placed in front of the object-glass of a telescope, is held close to the eye. In this case the eye itself takes the place of the telescope; and if we suppose the whole refraction to take place at the surface of the cornea, which will not be far from the truth, we must replace f by the diameter of the eye, and ψ by the angular extent of the portion of the spectrum considered, diminished in the ratio of m to 1, m being the refractive index of the cornea. When a telescope is used in this experiment, the retarding plate being still held close to the eye, it is still the naked eye, and not the telescope, which must be assimilated to the telescope considered in the investigation; the only difference is that ψ must be taken to refer to the magnified, and not the unmagnified spectrum.

Let the axis of x be always reckoned positive in the direction in which the blue end of the spectrum is seen, so that in the image formed at the focus of the object-glass or on the retina, according as the retarding plate is placed in front of the object-glass or in front of the eye, the blue is to the negative side of the red. Although the plate has been supposed at the positive side, there will thus be no loss of generality, for should the plate be at the negative side it will only be requisite to change the sign of ϱ.

First, suppose ϱ to decrease algebraically in passing from the red to the blue. This will be the case in Sir DAVID BREWSTER's experiment when the retarding plate is held at the side on which the red is seen. It will be the case in Professor POWELL's experiment when the first of the arrangements mentioned in art. 2 is employed, and the value of N in the table of differences mentioned in art. 5 is positive, or when the second arrangement is employed and N is negative. In this case ϖ is negative, and therefore $g' < -(h+k)$, and therefore (15.) is the expression for the intensity. This expression indicates a uniform intensity, so that there are no bands at all.

Secondly, suppose ϱ to increase algebraically in passing from the red to the blue. This will be the case in Sir DAVID BREWSTER's experiment when the retarding plate is held at the side on which the blue is seen. It will be the case in Professor POWELL's experiment when the first arrangement is employed and N is negative, or when the second arrangement is employed and N is positive. In this case ϖ is positive; and since ϖ varies as the thickness of the plate, g' may be made to assume any value from $-(4g+h+k)$ to $+\infty$ by altering the thickness of the plate. Hence, provided the thickness lie within certain limits, the expression for the intensity will be (16.) or (17.). Since these expressions have the same form as (1.), the magnitude only of the coefficient of $\cos g'$, as compared with the constant term, being different, it is evident that the number of bands and the places of the minima are given correctly by the imperfect theory considered in Section I.

15. The plate being placed as in the preceding paragraph, suppose first that the breadths h, k of the interfering streams are equal, and that the streams are contiguous,

so that $g=0$. Then the expression (17.) may be dispensed with, since it only holds good when $g'=0$, in which case it agrees with (16.). Let T_0 be the value of the thickness T for which $g'=0$. Then $T=0$ corresponds to $g'=-(h+k)$, $T=T_0$ to $g'=0$, and $T=2T_0$ to $g'=h+k$; and for values of T equidistant from T_0, the values of g' are equal in magnitude but of opposite signs. Hence, provided T be less than $2T_0$, there are dark and bright bands formed, the vividness of the bands being so much the greater as T is more nearly equal to T_0, for which particular value the minima are absolutely black.

Secondly, suppose the breadths h, k of the two streams to be equal as before, but suppose the streams separated by an interval $2g$; then the only difference is that $g'=-(h+k)$ corresponds to a positive value, T_2 suppose, of T. If T be less than T_2, or greater than $2T_0-T_2$, there are no bands; but if T lie between T_2 and $2T_0-T_2$ bands are formed, which are most vivid when $T=T_0$, in which case the minima are perfectly black.

Thirdly, suppose the breadths h, k of the interfering streams unequal, and suppose, as before, that the streams are separated by an interval $2g$; then $g'=-(h+k)$ corresponds to a positive value, T_2 suppose, of T: $g'=-(h\sim k)$ corresponds to another positive value, T_1 suppose, of T, T_1 lying between T_2 and T_0, T_0 being, as before, the value of T which gives $g'=0$. As T increases from T_0, g' becomes positive and increases from 0, and becomes equal to $h\sim k$ when $T=2T_0-T_1$, and to $h+k$ when $T=2T_0-T_2$. When $T<T_2$ there are no bands. As T increases to T_1 bands become visible, and increase in vividness till $T=T_1$, when the ratio of the minimum intensity to the maximum becomes that of $h-k$ to $h+3k$, or of $k-h$ to $k+3h$, according as h or k is the greater of the two, h, k. As T increases to $2T_0-T_1$, the vividness of the bands remains unchanged; and as T increases from $2T_0-T_1$ to $2T_0-T_2$, the vividness decreases by the same steps as it before increased. When $T=2T_0-T_2$, the bands cease to exist, and no bands are formed for a greater value of T.

Although in discussing the intensity of the bands the aperture has been supposed to remain fixed, and the thickness of the plate to alter, it is evident that we might have supposed the thickness of the plate to remain the same and the aperture to alter. Since $\varpi\propto T$, the vividness of the bands, as measured by the ratio of the maximum to the minimum intensity, will remain the same when T varies as the aperture. This consideration, combined with the previous discussion, renders unnecessary the discussion of the effect of altering the aperture. It will be observed, that, as a general rule, fine bands require a comparatively broad aperture in order that they may be well-formed, while broad bands require a narrow aperture.

16. The particular thickness T_0 may be conveniently called the *best thickness*. This term is to a certain extent conventional, since when h and k are unequal the thickness may range from T_1 to $2T_0-T_1$ without any change being produced in the vividness of the bands. The best thickness is determined by the equation

$$\varpi=-\frac{d\varrho}{d\xi}=\frac{\pi}{\lambda f}(4g+h+k).$$

Now in passing from one band to its consecutive, ϱ changes by 2π, and ξ by e, if e be the linear breadth of a band; and for this small change of ξ we may suppose the changes of ϱ and ξ proportional, or but $-\frac{d\varrho}{d\xi}=\frac{2\pi}{e}$. Hence the best aperture for a given thickness is that for which

$$4g+h+k=\frac{2\lambda f}{e}.$$

If $g=0$ and $k=h$, this equation becomes $h=\frac{\lambda f}{e}$.

The difference of distances of a point in the plane xy whose coordinates are ξ, 0 from the centres of the portions of the object-glass which are covered by the interfering streams, is nearly

$$\frac{\xi}{f}\left(g+\tfrac{1}{2}h\right)-\frac{\xi}{f}\left(-g-\tfrac{1}{2}k\right),\text{ or }\frac{\xi}{2f}(4g+h+k);$$

and if δ be the change of ξ when this difference changes by λ,

$$4g+h+k=\frac{2\lambda f}{\delta}.$$

Hence, when the thickness of the plate is equal to the best thickness, $e=\delta$, or the interval between the bands seen in the spectrum is equal to the interval between the bands formed by the interference of two streams of light, of the colour considered, coming from a luminous line seen in focus, and entering the object-glass through two very narrow slits parallel to the axis of y, and situated in the middle of the two interfering streams respectively. This affords a ready mode of remembering and calculating the best thickness of plate for a given aperture, or the best aperture for a given thickness of plate.

17. According to the preceding explanation, no bands would be formed in Sir David Brewster's experiment when the plate was held on the side of the spectrum on which the red was seen. Mr. Airy has endeavoured to explain the existence of bands under such circumstances*. Mr. Airy appears to speak doubtfully of his explanation, and in fact to offer it as little more than a conjecture to account for an observed phenomenon. In the experiments of Mr. Talbot and Mr. Airy, bands appear to have been seen when the retarding plate was held at the red side of the spectrum; whereas Sir David Brewster has stated that he has repeatedly looked for the bands under these circumstances and has never been able to find the least trace of them; and he considers the bands seen by Mr. Talbot and Mr. Airy in this case to be of the nature of Newton's rings. While so much uncertainty exists as to the experimental circumstances under which the bands are seen when the retarding plate is held at the red side of the spectrum, if indeed they are seen at all, it does not seem to be desirable to enter into speculations as to the cause of their existence.

* Philosophical Transactions for 1841, Part I. p. 6.

XVII. *An Experimental Inquiry undertaken with the view of ascertaining whether any, and what signs of current Electricity are manifested during the organic process of Secretion in living animals, being an attempt to apply some of the discoveries of* FARADAY *to Physiology**. *By* H. F. BAXTER, *Esq.*

Communicated by Sir BENJAMIN BRODIE, *Bart., F.R.S.*

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THE conjecture and experiment of WOLLASTON†, the cautious opinion of PROUT‡, the experiments of DONNÉ§ and of MATTEUCCI‖, are so well known that a mere allusion to them may be deemed sufficient. BECQUEREL¶, in speaking of MATTEUCCI's experiment, adds, "Si de nouvelles expériences confirment les résultats, il faudrait en conclure réellement que les organes qui sécrètent un liquide acide ou alcalin, ont des facultés électriques analogues à celles de la pile."

POUILLET** inserted one of the platinum extremities of a galvanometer into the jugular vein of a rabbit, the other into the carotid artery, without any effect being produced on the needle. MÜLLER†† says, "With the galvanometer no electric current can be discovered in the blood. I perceived no variation of the magnetic needle of the multiplier, even when I inserted one wire into an artery of a living animal, the other into a vein."

The galvanometer‡‡ that was used in these experiments is one of the common and ordinary construction, astatic, consisting of but few coils; the needles suspended by silk-worm silk, and the electrodes attached by screws. As the object was to ascer-

* It would be unjust to BECQUEREL not to state, that great and important assistance was obtained during the progress of the inquiry from his valuable work, entitled "Traité de l'Électricité," respecting one class of phenomena especially, viz. the action of an acid and an alkali upon each other when separated by a membrane or any other porous diaphragm. But, at the very commencement of the inquiry, it soon became apparent that no real progress could be reasonably expected until clearer ideas had been obtained as to the origin of the power in the voltaic circle. This led to the study of those admirable memoirs of FARADAY. The inquiry and the study of those memoirs went hand-in-hand. The opinions *supposed* were those from FARADAY; the experiments, tests of those opinions. The endeavour to master the *meaning* of that important, comprehensive, and expressive phrase, "*an axis of power having contrary forces, exactly equal in amount, in contrary directions*," was the mental difficulty; in *that* consists the requisite mental labour. It is not too much to add, that without those memoirs the inquiry would not have been continued.

† Philosophical Magazine, vol. xxxiii. p. 488. ‡ On Stomach and Urinary Diseases, 3rd edit. p. xxv.

§ BECQUEREL, Traité de l'Électricité, tom. i. p. 327. ‖ Ibid. tom. iv. p. 300. ¶ Ibid. p. 301.

** Journal de Physiologie, tom. v. p. 5. †† MÜLLER's Physiology, translated by BALY, vol. i. p. 148, 2nd edit.

‡‡ Made by NEWMAN of Regent Street. There is one advantage attending the use of a galvanometer that is not very delicate in its construction in these experiments; the vibrations of the needle soon subside, and consequently more information can be obtained from a single experiment.

tain, if possible, the existence of the current, an accurate description of its delicacy will not be necessary. It is sufficiently so to indicate the existence of a current during the combination of an acid with an alkali, such as very dilute solutions of nitric acid and of potash, when separated by a membrane.

In several unsuccessful experiments, the following electrodes were used:—Two platinum wires, $\frac{1}{24}$th of an inch in thickness and eleven inches in length, were pointed at one extremity, to be easily inserted into a blood-vessel or an organ, and coated with sealing-wax for about two inches, leaving the extreme point bare to the extent of one-fourth of an inch, the other extremities being attached to the galvanometer. But during the inquiry, in consequence of the stiffness of the wires forming the electrodes occasioning a motion of the whole instrument, when making and breaking contact, the following alteration was made in the arrangement. Thick copper wires ten inches in length were connected with the galvanometer by the screws, and each of the free extremities so bent as to rest in a separate wooden cup containing mercury. A platinum plate, an inch square, was attached to one extremity of each of the platinum electrodes to increase the extent of surface, and being placed in the wooden cups, a communication was formed with the galvanometer by means of the mercury, the pointed extremities serving, as before, to be inserted into the different parts of the animal. Great care was taken to ascertain that the different contacts were perfect, and no result upon the needle occurred from the whole arrangement, when a circuit was formed with a weak solution of salt, or water, previous to each experiment.

It will be unnecessary to relate the experiments, thirteen in number, upon cats, kittens, a guinea-pig and rabbits, in which an endeavour was made to ascertain whether the effect of a diverted current might not be obtained by inserting the electrodes into the portal vein alone, supposing that the stomach and liver formed poles similar to those of a galvanic circle; or whether a current might not be obtained by inserting them into the portal and hepatic veins. These failures, combined with theoretical reasoning, led to the supposition that the effect sought for existed in a different quarter. The inquiry will therefore commence with relating the last of the unsuccessful experiments.

Experiment 1.—Rabbit, six weeks old. (*a*). One electrode inserted into the vena porta, the other into the vena cava, at the entrance of the hepatic veins; no effect. (*b*). Caput coli, and a vein coming from the same part; a slight effect appeared: the electrodes were cleaned and reinserted, but the same effect did not occur. (*c*). Stomach and liver. (*d*). Stomach and vena porta. (*e*). Stomach and gall-bladder; no effect.

In these and the following experiments the electrodes were cleaned after the formation of a previous circuit, whenever the substances adhering to them might influence the result. Repeating the experiments of Matteucci and of Donné, only once did the effect occur, and that but slight, in the guinea-pig. The following fact may perhaps account for it.

Instead of the plates dipping into the mercury, the points were used for this purpose, and the surface of the plates served to form the free extremities of the electrodes.

The stomach was laid open, one of the plates pressed on the mucous membrane, the other upon the surface of the liver; a decided effect was now produced upon the needle, and by making and breaking contact so as to catch the vibrations of the needle, made to increase to 15° or 20°. The points were used as before; no effect. When the surface of the plate of one electrode was connected with the mucous membrane of the stomach, and the point of the other electrode with the liver, the effect upon the needle was greater than when the pointed extremity of the electrode was connected with the stomach, and the surface of the plate with the surface of the liver; in the latter instance the effect was very slight; but in neither instance was the effect so great as when both plates were used. The direction of the current, as indicated by the needle, was from the stomach along the metallic conductor to the liver.

The liver was removed and placed upon the intestines, the stomach remaining; the same actions occurred, but not to the same extent.

Stomach almost empty.

Considering that the failure in former experiments arose from the want of surface at the free extremities of the electrodes, the sealing-wax was removed.

Experiment 2.—Rabbit. The pointed extremity of one electrode was inserted into the caput coli, and pressed against the mucous membrane, the inferior mesenteric vein was wounded, and the plate of the other electrode dipped into the blood; the latter positive 5°, and made to increase by making and breaking contact.

An incision was made into the stomach, and the plate of one electrode inserted into it; the plate of the other lightly pressed on the surface of the liver; stomach positive 10°, and made to increase by making and breaking contact.

In cleaning one of the electrodes it broke, about half an inch from the plate. The plate of the electrode was in contact with the mucous membrane of the ilium, and the pointed extremity of the broken electrode inserted into a vein coming from the same part; blood slightly positive.

A platinum wire (No. 18), six inches in length, was flattened out at one extremity so as to present a surface three-fourths of an inch in length, and one-sixth of an inch in breadth. This will be called electrode A (E A). The former electrode with the plate attached, electrode B (E B). The broken electrode, having the broken extremity flattened out to the extent of one-fourth of an inch in length and to one-eighth of an inch in breadth, electrode C (E C).

In describing the circuits, when the pointed extremity is in contact with the animal, it will be stated the *p* of E A, &c., otherwise the broad extremity is used.

Experiment 3.—Rabbit. Mucous membrane of the ilium and vein from the same part; the *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive 4°; when E B was used a greater effect, and made to increase; no effect ensued when the *p* of E B was inserted into a different vein; returning to the former vein, the action upon the needle occurred; should the blood however from the two veins become mixed, then an effect upon the needle ensued, more especially if E B be used. No effect when E B was placed

on the outside of the gut over E A where the blood had not been, whereas with blood flowing from the vein, they may be separated to the extent of an inch or more, the effect occurring. Stomach and liver; the *p* of E A inserted into the former to the extent of an inch, E B lightly pressed on the surface of the latter; stomach positive 8°; an attempt was made to insert the *p* of E B into a vein coming from the stomach, but failed from the difficulty in obtaining a vein of sufficient size; when it was inserted into the portal vein, no effect. E C inserted into the caput coli; stomach slightly positive.

Experiment 4.—Cat. Prussic acid dropped on the nose. Mucous membrane of the ilium, and a vein from the same part; the *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive 5°, and made to increase: a vein coming from a different part was punctured, no effect: with the former vein the effect ensued, but not when it had become empty.

Mucous membrane of the stomach and blood from the same organ; the *p* of E A was in contact with the great curvature of the stomach to the extent of an inch, a vein corresponding to the lesser curvature was punctured with the *p* of E B; no effect: the portal vein was punctured at its commencement; as the blood flowed out a slight effect occurred, blood positive: E B was lightly pressed on the surface of the liver; the latter slightly positive.

Mucous membrane of the upper part of the colon, and vein from the same part; *p* of E A in contact with the former to the extent of an inch and a half, the *p* of E B with the latter; blood positive: E B pressed on the surface of the liver; the latter positive. The liver and intestines covered with blood.

The *p* of E A inserted into the stomach, E C into the colon; no effect.

Stomach and small intestines empty.

Experiment 5.—Cat. Killed as the last. In opening the abdomen the liver was wounded. The mucous membrane of the upper part of the small intestine, where active digestion was going on, was in contact, to the extent of an inch, with the *p* of E A; an artery going to the same part was punctured with the *p* of E B; no effect: when the vein was wounded, a decided result; blood positive. The inside and outside of the gut were formed into a circuit; no effect.

The mucous membrane of the stomach, in contact with the *p* of E A, to the extent of an inch, E B with blood flowing from the vena porta; blood slightly positive: placed on the liver; the same result, but not when the point was used. The liver covered with blood from the wound.

The pelvis and renal vein of the same kidney were formed into a circuit, with the *p* of E C and of E B; vibrations occurred, but impossible to obtain any decided effect by making and breaking contact.

Between the mucous membrane of the colon and vein; blood positive.

Stomach half-full of food.

The following experiment was to ascertain how far the different solid and fluid substances in contact with the electrodes might interfere with the result.

Experiment 6.—E B covered with some blood from the cat, was dipped with E A into water. A similar circuit was formed with fresh blood and water containing fæcal matter from the colon, the electrodes were close to each other. A portion of the colon of the cat, with its contents, was removed and placed in a weak solution of potash; E A and E B were dipped, one into the solution, the other into the gut, and then changed; in no instance did any effect occur. Some very dilute nitric acid was mixed with the contents of the colon and the same circuit formed; contents of the colon positive 3°. Can the difference, which is observed between cats and rabbits, as to the direction of the current when the stomach and liver are formed into a circuit, be attributed to the action of the poison, although no poison had been taken into the stomach?

Experiments 7 and 8 were upon rabbits; in one, prussic acid was used as in *experiment* 5; in the other, after a circuit had been formed between the mucous membrane of the stomach and blood flowing from the aorta, an opening was made and about ten drops of prussic acid poured into the stomach. The results only need be detailed. The mucous membrane of the stomach was positive to the following parts: surface of liver, mesentery, blood flowing from the vena porta and aorta, gall-bladder, mucous membrane of the duodenum and of the caput coli.

The blood flowing from the mucous membrane of the ilium and of the caput coli was positive to these parts from 3° to 5°.

The surface of the liver and the mesentery were slightly positive, when E B was in contact with them, to the mucous membrane of the ilium and caput coli.

In the following circuits no result was obtained:—Mucous membrane of the stomach and vena porta, the pointed extremity being inserted into the latter. Gall-bladder and vena porta. Mucous membrane of the ilium and that of the caput coli. Mucous membrane of the ilium and vein coming from the same part; this occurred when the aorta had been wounded, no blood flowed and the intestine was pale.

The contents of the stomach were positive to those of the colon when formed into a circuit out of the body; the effect was not so great as when the circuit was formed between the stomach and caput coli, the parts remaining *in situ*. In one experiment, the stomach, liver and intestines were removed from the body: the stomach was positive to every other part; it was detached, emptied of its contents, and washed, the same circuits then formed, but no effect; some of the food replaced, the former effects were reproduced, but not so decided. The caput coli was slightly negative to the liver and mesentery. With the small intestines no effect. In both experiments the contents of the stomach reddened litmus paper, and formed a coarse, dry, compact mass; those of the caput coli a soft homogeneous mass, but produced no effect either on litmus or turmeric paper. From these two experiments, the difference of effect between cats and rabbits, when the stomach and liver are formed into circuits, cannot be attributed to the action of the poison.

At the present stage of the inquiry we may be justified in drawing the following

inference:—*When the electrodes of a galvanometer are brought into communication, one with the mucous membrane of the alimentary canal, the other with the blood flowing from the same part, a deviation of the needle takes place, indicating that the secreted product and the blood are in opposite electric states.*

The two following *experiments* 9 and 10, upon rabbits, were undertaken to ascertain how far they would confirm this inference. To avoid unnecessary repetition, it may be stated, that the same results occurred as in experiments 7 and 8; and, in addition, the following circuits were formed.

Renal vein and pelvis of the same kidney; renal vein of the opposite kidney and urinary bladder: in both instances vibrations only were produced.

Mucous membrane of the stomach and bile flowing from the gall-bladder; the former positive.

Food from stomach and blood; former positive.

No result was obtained in the following circuits:—Gall-bladder and vena cava at the entrance of the hepatic veins. Gall-bladder and vena porta. Mucous membrane of the ilium and superior mesenteric artery. Stomach and gall-bladder (the pointed extremity being inserted into its whole length). Mucous membrane of the stomach and vena cava at the entrance of the hepatic veins. Mucous membrane of the stomach and vena porta. Contents of caput coli and blood. Mucous membrane of the ilium and blood on its outer surface.

In one experiment the liver was much diseased, dark-coloured, and half the usual size; the rabbit appeared weak and unable to support itself.

The parts in the last experiment were covered over with a towel and allowed to remain undisturbed for eight hours. It will be unnecessary to state the circuits that were then formed, with their results, and likewise those in a rabbit, which died from natural causes, twenty-two, twenty-five, and thirty-nine hours after death, as the following experiment containing the principal facts worthy of notice will be related at full length.

Experiment 11.—Rabbit six hours after death, which arose from natural causes. The surface of the viscera and contents of the abdomen were remarkable for their appearance, being so similar to that of a healthy and live rabbit. The veins being full of fluid blood, a favourable opportunity occurred of ascertaining whether the same effects would be produced as in the living animal.

The following circuits were formed:—The blood flowing from the ilium, an empty portion of the descending colon, and caput coli and the mucous membrane of these parts; in the latter only did any effect occur, the mucous membrane slightly positive.

Contents of the caput coli produced no effect on litmus paper.

Mucous membrane of the stomach and the following parts, surface of the liver, mesentery and small intestines; each of the latter slightly positive.

Food in the stomach acid: the moisture covering the different viscera restored the slightly reddened litmus, but produced no effect upon turmeric paper.

E A inserted into the centre of the mass of food in the stomach, E B lightly pressed on the upper external surface over E A; E B slightly positive: E B placed on the liver or intestines; E A slightly positive.

E B and the broken plate of E C were placed, one on the upper surface of the stomach, the other on the mesentery; no effect. Some food was taken out of the stomach and placed on the intestines, the broken plate on the mesentery, E B on the food; E B positive. The same arrangement was made with some of the contents of the caput coli; the latter slightly positive.

The following circuits were formed: food from the stomach and contents of the caput coli; the former positive: some food from the centre of the mass in the stomach, and some in contact with the mucous surface; the latter positive. The mass in the stomach was coarse, dry and compact; that in the caput coli of a finer and softer consistence.

The parts were covered over with a towel for twelve hours.

E B placed on the upper external surface of the stomach, E A inserted into the caput coli; E B positive. E A remaining, E B on the small intestines; effect very slight.

E C inserted into the centre of the contents of the stomach, E B lightly pressed on the upper external surface; E C positive. The stomach was moved over and E B placed on that which had been its inferior surface; E B positive: E B was placed on the part where the stomach had been lying; E B positive.

The different parts had become more moist.

No doubt can exist as to the cause of the production of the effects obtained in the last experiment, viz. the difference of the fluids and solids in contact with the electrodes. The proposition, that, when two heterogeneous fluids are separated from each other by a membrane, or any other porous diaphragm, that which performs the part of an acid takes positive electricity, the other, that of an alkali, takes negative electricity, has been well established by Becquerel*. The results observed in the last experiment beautifully illustrate it; and at the same time show how impossible it is to say, *à priori*, what would be the effect upon the needle when the electrodes are inserted into different parts of a dead animal. The mere circumstance of placing the electrodes in contact with different portions of the contents of the stomach produces an effect or not upon the needle; the state of the parts as to moisture, and the transudation of the secreted fluids or contents through the walls of the different viscera; the contents of the colon and of the stomach considered as a mass, forming one conducting body; the difference with respect to the extent of surface of the electrodes; each of these circumstances may be readily seen to be influential and unnecessary to particularize. There may be two or three acting points between the electrodes, determining the current in opposite directions, or assisting each other, the action upon the needle being the result of a differential, or of a combined current, according to circumstances.

Shall we be justified in referring the effects observed in experiments 2, 3, 4, 5, 7

* Traité de l'Électricité, tom. iii. p. 387. v. part. ii. p. 192.

and 8 to the same cause? Let us take the simple fact, that, when the mucous membrane of the small intestine and the blood flowing from it are formed into a circuit, a deviation of the needle amounting to 3°, 4° or 5° is obtained, the intestine being empty and therefore uninfluenced by the circumstances we have just now mentioned; why did the effect not occur in experiment 11? the conditions appeared to be precisely similar; or in experiments 7 and 10, when the artery was wounded; or in experiments 3 and 4, when blood flowing from a different part formed the circuit; or in experiments 3, 5, 9, when a circuit was formed between the inside and outside of the gut? Did not the failure arise in these instances in consequence of the absence of one necessary condition, the flowing of the blood from the same part, the transmission of the carrying particles from one electrode to the other, as shown in experiments 2, 3, 4, 5 and 7?

Without entering into any discussion as to the mode in which the effect may be supposed to be brought about in the living animal, and the difference observed when the stomach and other parts were formed into circuits in rabbits, and when the same circuits were formed in cats, we may be justified in adding the following to our former inference, viz. *that the effect is produced during the organic action of the part, it ceasing after the death of the animal.*

Instead of endeavouring to refute the notion that the stomach and liver form poles similar to those of a galvanic circle, let us briefly allude to the experiment and conjecture of Wollaston. Was not that experiment to *illustrate*, rather than to prove his conjecture? and are not these experiments identical with that conjecture? He evidently saw, mentally speaking, the *meaning* of that phrase "an axis of power," &c. This inquiry has been undertaken with the advantage both of Faraday's labours and the use of the galvanometer. Wollaston's conjecture and experiment have existed for forty years.

The following is a brief recapitulation of the general conclusions which may be deduced from the foregoing experiments and reasonings:—

1. When the electrodes of a galvanometer are brought into communication, one with the mucous membrane of the alimentary canal, the other with the blood flowing from the same part, a deviation of the needle takes place, indicating that the secreted product and the blood are in opposite electric states.

2. That the effect occurs during the life of the animal, it ceasing after its death.

3. That the effect may be considered as arising from the decomposition of the blood; *i. e.* the changes which occur during the formation of the secreted product and venous blood.

4. That these changes are effected by the *organic action* of the part.

The author begs to acknowledge the great kindness that he has received from Sir B. C. Brodie, Bart., and from Dr. Todd.

12 *New Burlington Street.*

Explanation of the Woodcut.

Fig. 1. Wooden mercurial cup.

Fig. 2. Copper wire to form the communication between the galvanometer and mercury.

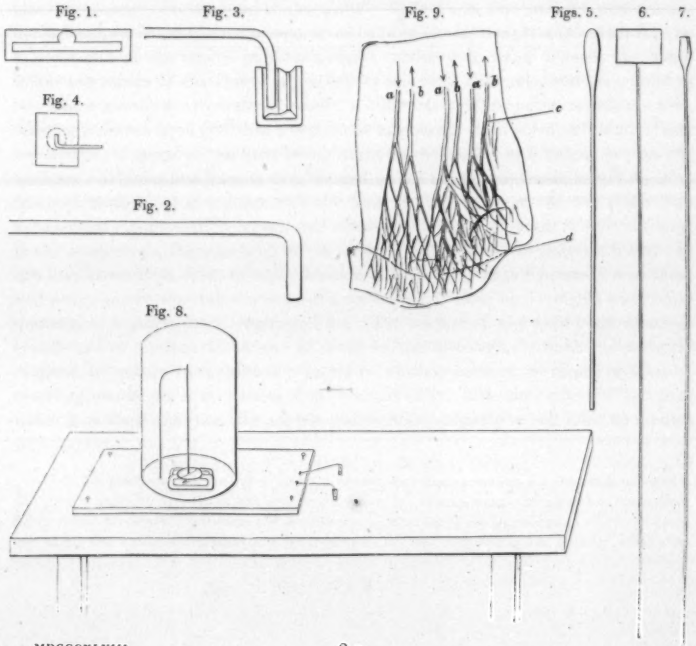
Fig. 3. A section of the mercurial cup, showing the mode in which the thick copper wire was connected with it.

Fig. 4. Shows the manner in which the plate of platinum was soldered on to the platinum electrode, pure gold being used; all the part within the dotted line, and for a short distance up the wire, was coated with shell-lac to prevent the action of the mercury upon it.

Fig. 5. Electrode A. Fig. 6. Electrode B. Fig. 7. Electrode C.

Fig. 8. The arrangement with the galvanometer previous to each experiment.

Fig. 9. *a a a*, arteries; *b b b*, veins; the arrows indicate the course of the blood: *c*, point of the electrode in contact with the wounded vein; the dotted line of *d* the electrode in contact with the mucous surface of the small intestine.



XVIII. *On the Direction assumed by Plants.* By *Professor* Macaire *of Geneva.* *Communicated by* P. M. Roget, *M.D., Sec. R.S.*

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§ 1. *On the Curling-up of Tendrils.*

The plants with tendrils are very numerous. According to Mr. Palm there are about five hundred, divided into seventeen families. Of these, one hundred and sixty have a ligneous stem, eighty-three are perennial herbs, and one hundred and seventeen are annuals.

My experiments on the mode of curling-up of these organs were made on the tendrils of the *Tamus communis**, a plant of the family of the Asparageæ. The tendrils of this plant seem to be a thread-like degeneration of the footstalk of a leaf, whose place they occupy on the stem of the plant. They are at first straight, and are implanted perpendicularly on the stem, so as to form almost a right angle with it; the extreme end of the tendril only has a slight tendency to bend towards the stem. When the tendril of the Tamus is touched by any solid body whatever on a point of its surface not too far from the extremity, it contracts itself from the outside inwards, forming at first a hook and then a curl, so as to embrace the body closely if that body be circular; if angular, the knot is only tight on the angles, and bulges out on the surfaces. When a first knot is tied, the end of the tendril continues to roll itself up in a coil, though not in contact with the body in that part, and the coil slides over the external object, coming nearer and nearer to it so as to embrace it several times: in the mean while, the other end of the tendril continues also to contract itself. In this way as many as seven or eight knots are formed. I have frequently seen three tied before my eyes within the space of a quarter of an hour on a metallic wire, small branches of wood, a pencil, my finger, &c. The contact of any solid body whatever is sufficient to produce this effect; so much so, that although the tendril is evidently destined by nature to support the creeper to which it belongs, by means of the surrounding plants, yet if it chances to meet a part of the very same plant of Tamus of which it is itself a portion, the contact causes it immediately to roll itself up around that portion.

* Since this paper was read the author has been informed that *Tamus communis* is a plant without tendrils. The plant on which he made the experiments here referred to is a common weed in the gardens in Switzerland. Being without the means in this country of identifying it, he must supply the information on a future occasion, only adding that *Smilax aspera*, another of the Asparageæ, has been suggested to him as being probably the plant.

The tendril of the Tamus is very smooth, and its surface contains neither resinous nor glutinous matter, nor hair of any kind. When slightly rubbed between the fingers, it does not contract itself. To obtain its curling up, it is necessary that the contact should be only on one side. If the solid body round which the tendril had begun to coil be removed, it continues to contract itself in the air, but without fastening the knot on itself, the empty ring remaining constantly open. If, after a little time, an object of suitable size and form be introduced in this empty ring, it contracts anew and the knots tie themselves firmly on this new body.

If the tendril be left without internal support after its contraction, it does not turn again, nor resume its primitive direction in a straight line; on the contrary, the contractions are soon extended over the whole of the tendril so as to give it the appearance of a corkscrew.

The same thing happens to those tendrils the extremities of which are attached to a supporting body. This arrangement has the effect of preventing the tearing of the tendril when the plant is shaken by the wind, by giving it the shape and elastic properties of an helicoidal spring (*ressort à boudin*). I placed a small portion of a branch in contact with a tendril of Tamus; when it had begun to contract itself and the first knot had been tied, I let the branch go and it remained suspended. Not only did the tendril support the weight of the branch, but it continued to roll itself up around it, raising it more and more by each knot. Ten rings were thus formed around the slip, regularly arranged in a spiral by the side of each other. The branch was entirely covered over by them, and as there was no room for more, the tendril continued to contract itself in the air towards its base, and to form empty rings in the form of a corkscrew, having nearly the same dimensions as those on the branch.

When a body, such as an iron rod, too heavy to be supported, is placed in this way, the knot formed becomes loose and the rod drops. If the tendril rolls itself round a body that is soft and not elastic, such as a piece of packthread, it presses it tightly enough to render its diameter visibly less in the part where the knots are tied. This pressure may even be rendered sensible to the touch if the knot be suffered to form round the finger, and it goes on increasing to a certain extent.

When the tendril lays hold of an elastic body having a conical shape, such as the flat part of a leaf rolled up in a funnel, the knots slide over the leaf as they are formed and suffer it to escape. When a tendril of Tamus has begun to curl near its extremity and to fasten itself round any object, if the upper portion of the same tendril chance to meet with another exciting body, another part of the same branch for instance, it may curl over again in a spiral at this point and tie its knots there. The same thing may happen a third time; and in this way may be seen in the same tendril two or three portions closely wound round an object, while the remaining part of the tendril is loose and detached. The contraction of the tendrils of the Tamus always takes place in the same direction, and the curling is turned inwards, whether there be or be not an object round which it may occur: and more than this, when a round

body is put in contact with the external surface of a tendril in its straight form, it does not curl round the body which excites the movement, but on the contrary from the outside inwards, although there is nothing there for it to embrace.

This tendency to curl only on one side has induced me to examine the tendrils, to see whether I could discover by means of the microscope a special anatomical structure that might explain this peculiarity.

I have made observations with the microscope of Amici and a magnifying power of 800 times on very thin slices of the tendril, taken some from the external, and some from the internal side. When the specimens were cut out of tendrils already contracted in a spiral form, the only visible difference was that the cells on the internal side appeared very little elongated and almost square; while, on the contrary, they were much narrower and longer on the opposite side. But this appearance was evidently mechanical and produced by the contraction itself; for when I examined slices cut in all directions from tendrils still in their straight form and not contracted, I found the anatomical structure to be precisely the same in all, and indeed similar to that of those leafstalks of the same plant which are not susceptible of being curled up.

I caused a straight tendril of Tamus to curl by the excitement occasioned by the touch of a pencil. Two knots were closely tied within the space of ten minutes. I then cut out the tendril near its base, so as to interrupt its communication with the plant; the tendril, though kept in the light and in a warm and damp atmosphere, did not continue to curl itself.

When a straight tendril of Tamus is placed in a tumbler full of water, so as not to touch its edges, it does not experience any contraction, but is just as ready as before to curl up by the first contact of any solid body.

I have immersed a tendril many times over in a solution of gum-arabic, leaving it to dry between each successive immersion, so as to form round it a thin coat; the tendril so covered had not in any degree lost its power of contraction by the contact of a solid body, and the coat of gum did not seem to prevent the close adherence of the knots.

Liquid ammonia in a diluted state has no influence on tendrils. Alcohol and eau de Cologne seem to possess a slight exciting influence on the contraction of tendrils, which are thereby bent in the form of a bow, but do not continue to curl, and they appear not to experience any bad effects. When immersed, with the same precautions, in sulphuric acid diluted with water, the tendril contracts itself immediately and energetically. It curls up in a spiral form, though there be no object present round which it might roll itself. The knots, at first very loose, continue to tighten up to a certain point, although there always remains an empty space in the middle of the rings. After some time, the part touched by the acid becomes disorganized and dries up.

Diluted nitric acid has the same effect as sulphuric acid, but the contraction is

less rapid. The fumes that escape from the acid, without any actual contact with the liquid, cause the tendrils to contract and curl in the air, though in a less prompt and energetic manner than when immersed in it. The parts of the tendril that have been steeped in nitric acid, are afterwards found withered and dead. The tendrils, on the contrary, that have curled up by simple exposure to the nitrous vapours do not wither.

A solution of corrosive sublimate seems slightly to excite the contraction of the tendrils of the Tamus; but after a few hours the tendril so treated withers and dies.

I immersed in prussic acid, prepared by Scheele's process, a tendril of Tamus in its straight and vigorous state, carefully preserving it from contact with the vessel. I kept it there for two minutes and then took it out. The tendril did not seem to have experienced any alteration; but when I placed in contact with it a foreign body to excite it to curl up, no contraction could be produced; and although the tendril was to all appearance fresh and healthy, it could not be made to curl round. When a tendril that has been previously excited and has begun to curl itself in a spiral form is plunged into prussic acid, it loses the power of continuing its contraction, and the knots that were commenced do not become tied. Two days after such an experiment a tendril was found precisely in the same state in which it had been left, although the curling had begun on a branch of proper size, and the tendril appeared endowed with complete vegetative power. I tried if I could destroy with ammonia this narcotic influence of prussic acid, but without any decided results. A fresh and healthy tendril of Tamus was excited till it began to curl, and then immersed for two minutes in prussic acid. The knot in its incipient state was placed on a branch of precisely the same size as that by which it had been excited, and I observed every hour what took place. During five days that the experiment was followed up, no change was produced: the knot begun did not become tighter, nor was any other knot formed. The tendril remained to all appearance perfectly healthy; but the prussic acid seemed to have destroyed in it all power of contracting farther. These experiments require to be continued and multiplied; but they warrant the conclusion, that whatever be the cause of the irritability of the tendrils, their curling-up cannot be explained, as Knight thought, by the unequal action of the light on both sides of the tendril; nor as Decandolle admitted, by the obstacle afforded to vegetation by the contact of the leafstalk with the body on the side where it touches it. The rapidity of contraction in the tendrils of the Tamus cannot be accounted for by so slow a process. This irritability is a vital property inherent in the organ itself, but which ceases when it is separated from the parent plant, and which, as I have already shown to be the case with those plants called sensitive, is excited, modified, and even suspended or destroyed by the influence of poisons, either of the vegetable or mineral kingdom.

§ 2. *On the Inclination of Stems towards the Light.*

Every one knows that the branches and green parts of plants have an invariable tendency to direct themselves towards the most luminous quarter of the place in which they grow. The experiments of M. Teissier, who caused plants to vegetate in a cellar where they received air by an opening that did not give light, and light by a window which did not admit air, have shown that it was really light and not air that the plants were in search of. Decandolle imagined that he could account for this phenomenon by the inequality of the development of a plant that receives light only on one side. The lighted side, he says, decomposes more carbonic acid, solidifies a larger portion of carbon in its tissue, and becomes more solid; at the same time it exhales more water, and consequently contains more of the inorganic matter left behind, which contributes to harden it still further. The other side remains softer, the fibres are more elongated, and the consequence is the bending of the branch towards the side which is least elongated, that is to say, towards the light. This illustrious botanist has extended the same reasoning to the curling of tendrils; but I have already attempted to show that it could not be applied to this rapid physiological action in those of the Tamus.

It was necessary to investigate if there exists a special attraction exercised by light on the green parts of a plant, and in particular if a plant so placed as to be able to move, could be brought to change its position under the influence of light. My experiments on that head have been made under two circumstances of a different nature.

The subjects of the first were some special plants of the family of the Nayadeæ, the *Lemna minor* and *Lemna polyrhiza* (duck-weed), which naturally float on the water. These plants form a kind of anomaly in the vegetable kingdom, in as far as they consist of a single floating leaf, having submerged roots and producing at their margin new leaflets that often detach themselves from the mother plant, like the polypus, to form a separate individual; they are in consequence viviparous. I have nevertheless ascertained by experiment that they receive from the action of light the same influence as other plants; thus, if left on the water in complete darkness, the new leaves that shoot appear blanched and yellowish. If immersed entirely in spring-water and exposed to the rays of the sun, they remain green and vigorous, and emit a great quantity of bubbles of oxygen gas that gathers by degrees in the upper part of the bell.

I arranged an oval and elongated vessel so that, being half-full of water, one-half of it was kept in darkness by means of a diaphragm which was placed in the middle, and kept one line above the surface of the water. The part of the vessel that was intended to be kept dark, was carefully covered over with many sheets of black paper: the other half of the vessel was freely exposed to the influence of light. The apparatus was arranged in a locality perfectly free from disturbance and from

the agitation of the wind. A great number of floating plants of Lemna were successively placed in the dark part of the vessel. Though they could freely move on the water by the smallest impulse, I never saw them come near the lighted part or move into it, even when the experiment was continued long enough to allow the symptoms of blanching, already mentioned, to manifest themselves in the Lemnæ. No motion towards the light was ever perceived. It is to be understood that, for such a result, it is necessary that there should not be any possibility of shaking or vibration in the liquid, and a first experiment, undertaken without sufficient precautions in that respect, gave results by which I was at first deceived. My doubts on this result were excited by the following experiment. In a tumbler completely covered with thick black paper, I put some water on which I placed a few floating plants of Lemna. A narrow slip was cut out in the paper on the side opposite to the light, so as to bring a single ray across the vessel. The apparatus, covered over with a thick book, was left in a place not exposed to vibration. The Lemnas did not change the position which they had been placed in, and, far from arranging themselves, as I expected, in a line along the luminous ray, they did not move at all towards the illuminated space. Varied in different ways, the experiments with the Lemnas have always given negative results to the supposition that they have a real attraction exercised on them by light.

I have endeavoured to repeat the experiments on other plants. I have ascertained that seeds of peas, French beans, mustard, &c. put on floating pieces of cork in a vessel filled with water, not only did germinate, but that the plant produced could develope itself without any other care than replacing the evaporated or absorbed water. It could thus furnish a complete vegetative course, expand its leaves, make its flowers blow, and even bring its fruit to maturity; only the stems are very slender and the leaves smaller than usual.

The germination of seeds took place pretty nearly in the same way, whether they were exposed to light or kept in complete obscurity. As it had been said that light exercises an influence on the direction of roots, I made an experiment with four peas, placed on floating pieces of cork. The first (No. 1) was left to germinate and grew in a common glass tumbler; the second (No. 2) in a tumbler covered with black paper, but leaving a thin stream of light to enter by a slit in the paper; the third (No. 3) in a glass coloured blue, and admitting only a thin stream of blue light; and the last (No. 4) was kept in complete obscurity. The seed in the free light developed itself well, and in twenty-four days exhibited a strong stem of a fine green colour, five inches long and well-stocked with leaves. Nothing remarkable occurred in the roots.

No. 2, receiving only a ray of common light, germinated well and reached its full growth. After eighteen days its stem was four and a half inches in length. The root was very long, six inches at least, and was covered with small branching roots, which had all been formed on the side of the opening that admitted light, and had directed

themselves towards it. I turned the plant over so as to place the side of the large root deprived of small radicular threads opposite to the luminous slit. Five days afterwards, radicular fibrils had sprouted on that side; and those which had developed themselves before, had indeed not perished, but had ceased to grow. The experiment was completed after thirty-four days. The root was then a foot long, was covered on all sides with radicular threads, and had turned itself into a spiral form. The stem was slender, very little coloured, and had a length of ten inches and a half.

No. 3, receiving the blue rays, had, after eighteen days, a stem only three inches long, and the root measured four inches. The radicular threads were all on the side opposite to the slit giving admission to the blue light. I changed the position of the plant, and placed the radicular threads on the luminous side. Thirty-four days from the beginning of the experiment, radicular threads had sprouted on the side of the root where there were none before, and the root had also taken a spiral shape. It was seven inches long; the stem, nine inches long, was very slender and almost white.

No. 4, in the dark, germinated after five days, but a few radicular threads alone developed themselves without a stem.

These trials were repeated on peas and mustard-seeds, and gave results of the same nature, as far as concerns the curling of the roots in a spiral shape under such circumstances, and the tendency of the white light to favour, and of the blue light to hinder, the growth of radicular fibrils.

The experiments relating to the direction of the stems were made pretty nearly in the same way as with the Lemnæ; only the vessel in which the floats were placed was much larger, and the diaphragm was not so near the surface of the water. The consequence was that the darkness of one-half of the vessel went on increasing from the diaphragm towards the extremity of the covered portion, and though very intense at that last part, was nevertheless not complete. As soon as the seeds had germinated, they were placed on the cork floats, in which I had bored a hole through which the root emerged into the water. The float was placed in the dark part of the vessel, far enough from its side to avoid the capillary attraction, and it could be moved by the gentlest impulse. It is hardly necessary to say that the apparatus was kept perfectly free from shaking or from the action of the wind.

On the 14th of May, a pea in germination was placed on the float in the dark part of the vessel: it grew very slowly, and on the 22nd began to exhibit a very short and almost white stem. This stem by degrees became longer and longer, spreading itself along the surface of the water, and on the 8th of June it had reached the diaphragm. It formed then a long stem, etiolated, slender and white, running along the surface of the water; its length was two feet. The cork float had not moved forwards a single line towards the luminous aperture; only the weight of the plant throwing itself, as it were, all on one side, had by degrees bent down the cork float, but on the same spot it before occupied. When once the stem of the pea had

passed under the diaphragm and had reached the illuminated part of the vessel, it grew in an erect position, became green, and began to develope leaves.

This experiment, very often repeated with peas, French beans, &c., always gave similar results. Never did any attraction of the whole plant towards the light manifest itself; and however long a stem it might be necessary to produce in order to reach the diaphragm, that was always the means to which the plant had recourse.

In order to vary the mode of experiment, I placed on a cork float in the obscure part, a plant of French beans already developed, green and strong, and the roots of which were immersed in the water. The green stem took little or no ulterior development; but from the neck of the root there grew out another stem, white and etiolated, that spread itself along the water to reach the diaphragm and the light portion of the vessel; there it grew erect and gave forth its leaves. The float had not changed its place, and, as before, had only been bent down by the weight. The same experiments repeated with green and vigorous peas, gave precisely the same results.

Germinated seeds of mustard placed on very light floats in a tumbler half-full of water and surrounded with black paper, so as to admit only a luminous ray, were put in the dark portion, but very near the aperture. One of the plants grew and sprouted a stem that went all round the tumbler to come and spread its leaves in that part of the vessel where the luminous aperture was, and once there, the plant did not pass beyond that point. It grew erect in that part, though the light was too weak to render it entirely green. No motion was perceptible in the float; and it is very remarkable that, being close to the luminous aperture, the plant in search of the light had taken this long circuit rather than communicate to the float the slight motion that would have placed it in possession of it. I venture to conclude from these experiments, that the direction of plants towards the light is not the result of an attraction, properly so called, which, similar to the physical attractions, could carry over the attracted body towards the agent.

The ingenious supposition of Decandolle of a mechanical bending, due to a greater solidification of the fibres on the light side than on the other, appears to me not to be more applicable to the direction of stems towards the light, than to the curling of tendrils; for, by the arrangement of the apparatus, the lightest side was not always the same, and the stems advanced straight towards the light without incurvation or bending.

There remains to examine the hypothesis of Dutrochet, who admits that there exists in the stems and branches of plants a system of cells progressively increasing in size from the centre to the circumference in the central parts of the stem, and from the circumference inwards in the cortical portion. He supposes that these cells are gorged with sap by the influence of endosmose, and that this endosmose tends to give a bending in contrary directions to the two systems, so that the stem is inflected in the direction that predominates. He admits too the existence of a fibrous system

placed in the central cellular organization, and supposes that its fibres are also decreasing in size and are inflected by being filled with gas or oxygen endosmose. The incurvation of this tissue always takes place inwards, and that of the cellular system outwards. According to Dutrochet, the influence of light has a tendency to diminish the filling up of the cells and impair their power of incurvation, and, on the contrary, to increase the production of oxygen gas that creates a bending in the opposite direction in the fibrous tissue. He has grounded this theory on some curious experiments. For instance, by cutting in a longitudinal direction a stem of *Medicago sativa* bent towards the light, he saw that the part of the stem which had been in the light increased its curvature, while the other, on the contrary, became first straight and then bent in an opposite direction. There was then, according to him, an antagonism between the two slips, and this fact was sufficient to overthrow Decandolle's theory, in which, as the exterior slip is supposed to be the only active one, its incurvation ought to have been preserved or even increased in the primitive direction. I have repeated the same experiment with the same result on many stems or footstalks, among others on the footstalk of the leaf of *Calla æthiopica*. But in trying to repeat the sections in all directions, I observed that the bending of the slips was always towards the bark, or outwards, and that the position of the stem with regard to the light had nothing at all to do with it. This phenomenon is due to the contraction or the resistance to any elongation of the exterior cuticle.

Thus, when a segment of stem or footstalk is immersed in water with its cuticle entire, the liquid, penetrating into the cells, fills the cellular tissue, renders it turgid, and there results an elongation of the central parts; but as the fibres of the cuticle cannot follow this elongation and therefore resist it, the segment of stem or stalk is inflected towards the resisting side, or the cuticle, and the incurvation becomes manifest outwards. If, leaving the central cellular system entire, I only removed the cuticle, the immersion of the slip in water, though it brought on the turgid state, did not create incurvation, which yet ought to have appeared if it were, as Dutrochet supposed, a necessary result of the cells decreasing in size. The same consequence followed when the segment was immersed in water after the cuticle had been slit in two or three places, taking care that the incision did not go beyond it; the imbibition took place, the cellular system was swollen and elongated, but the stem remained straight because the cuticle no longer presented any resistance.

The cuticle alone put into water curls by the shortening of the fibres pretty nearly like a wet rope, so that, far from lengthening it, the liquid has a tendency to shorten it.

Besides, Dutrochet's hypothesis that light has a tendency to diminish the endosmose by the vacuum produced by the exhalation in the cells, appears not to agree with the supposition of the same author, by which he attributes the ascension of the sap to endosmose. He admits that it is through the cellular membrane of plants and by endosmose from cell to cell that it produces the ascensional march of sap, a

liquid which he supposes to be inferior in density to that inclosed in the cells. In the endosmose experiments it is usual to take liquids rather different in their specific gravities; and it seems that if we admit that the sap contained in the cells of the upper part of the plant, where it has been already elaborated, may have a specific gravity sufficiently greater than the surrounding water to let it come in by endosmose, it is not so easy to understand this difference of density from cell to cell as being sufficient not only to allow endosmose to take place, and still less to produce the enormous ascensional power which is admitted to exist in the sap. It occurred to me that the effects of endosmose in such a case might be ascertained by means of experiments.

I took three glass tubes of unequal diameters, such as could be put one inside the other. One of the apertures of each tube was closed with a piece of bladder, and after a solution of sugar of 1·13 specific gravity had been introduced into them, they were placed the one within the other: the last or largest tube was dipped in pure water. The height of the liquid in each tube was carefully ascertained, and the endosmose then observed. The liquid in the largest tube did, as usual, increase in bulk by the replenishing endosmose of the water outside of it, and the effect went on gradually increasing for several days. But during this time, the liquid of the two other tubes did not experience any change of level, the difference between the respective densities of the solutions they contained and the liquid of the larger tube not being sufficiently great to produce endosmose. This experiment, many times repeated, both with alcohol and with solutions of gum or sugar, always gave the same result, and seems to show that a succession of cells would not act otherwise. The transmission of a liquid from one to the other by way of endosmose either would not take place, or at all events would be too slow to account in any manner for the rapid ascent of the sap.

In repeating Dutrochet's experiments on the turgid state that the cellular tissue of plants takes in water, and employing for that effect coloured liquids, it occurred to me, that the absorbed liquor was not inside the cells themselves, but in the intercellular spaces, which accords with the rapidity of the result, which it would be impossible to understand if the liquid were to proceed from cell to cell and through their walls.

It occurred to me also, that if endosmose was the only or principal agent of the ascension of the sap in plants, that is to say of vegetation, this phenomenon ought to be influenced by the two indispensable agents of vegetation, heat and light. As there is something rather mysterious in the phenomenon of endosmose, it was not impossible that such might be the fact. Dutrochet, from an experiment on the cæcum of a fowl, concluded that a rise in the temperature increased both the rapidity and the quantity of endosmose. In his experiments on acids he even announces having discovered that the temperature changes the direction of endosmose, which goes from the water towards the acid, or from the acid towards the water,

according as the thermometer is low or high. At all events he does not generalize this singular result, which, according to him, belongs only to the acids; but as a great many saps have an acid reaction, the result ought to be, that, according to the state of the temperature in those cases, the sap should enter the tree or flow out of it: this seems to be in opposition to all known facts.

In all the experiments I have tried, and they have been numerous, I have never been able to ascertain that heat had any apparent influence in promoting endosmose. It is obviously necessary to deduct the effect produced by the dilatation of the liquid by the caloric, or wait until it has returned to its previous temperature, before measuring its bulk. With this precaution, the quantity of water introduced into tubes perfectly similar and containing the same solution of sugar, was found to be exactly equal in the same time, though one of the tubes was maintained at a temperature of 65° C. (149° Fahr.) and the other at 10° C. (50° Fahr.). The ascent of the liquids by endosmose proceeded at exactly the same rate when the tube was kept at a constant low temperature as when it was much more heated, and then brought back again to the usual temperature of the atmosphere. Heat does not appear to me to have any influence in increasing either the quantity or the rapidity of endosmose.

Similar experiments were made, preserving for the endosmose apparatus the same temperature, but exposing one to the influence of light and keeping the other in complete darkness. The tubes and the liquids were absolutely similar, and there was no difference whatever found in the rapidity or quantity of the ascent of the liquid in the tube. When the same endosmose apparatus was exposed alternately to light and to darkness, the same decreasing rate of the endosmose was observed that would be seen in an apparatus constantly kept in darkness or in the light, and no special influence of light could be discovered. Thus, to give an instance of one of the numerous experiments performed, the mean rising of the liquid in an endosmose tube has been in lines,—

		Lines.
During one hour	in the light	3
	in darkness	1·9
	in light	1·8
	in dark	1·8
	in light	1·7
	in dark	1·7
	in light	1·2
	in dark	1
	in light	0·7, &c.

Many times repeated, and with various liquids, these experiments have always given the same results; and I think I am entitled to conclude from them, that heat and light have no apparent influence on the endosmose phenomenon.

There appears to me, from all these facts, very little probability that endosmose

actually performs in vegetation, and in particular in the direction of stems, the important part that has been attributed to it.

§ 3. *On the Direction of Leaves.*

It is known to every one that the leaves of plants have a tendency to assume the same constant position with respect to their two surfaces. One of these surfaces is generally of a deeper green, smooth and glistening*, the nerves of the leaf being very little if at all prominent; this is the surface naturally turned to the sky, and it is on that account called the upper, or superior surface. The other is of a paler green colour, full of little asperities or covered with short hair; it has little or no varnish, and, as it is naturally turned towards the earth, it is called the under, or inferior surface. As far as regards the anatomical structure, M. Adolphe Brongniart has found out that the under surface of leaves contains a greater quantity of pneumatic cavities communicating with the external air by the apertures of stomata than the upper surface. It is to this accumulation of air that they owe, it seems, their whitish colour; and some leaves, like those of French beans, when placed in water under a vacuum, allow this air to disengage itself through the stomata, and, as it is replaced by water, the inferior surface of the leaf becomes of the same green colour as the upper surface. A long immersion in water without having recourse to a vacuum causes the air gradually to replace that liquid, and gives an uniform colour to the two surfaces of the leaf. In some leaves, in those of the Grasses for instance, there is hardly any difference between the two surfaces. In aquatic leaves, as in those of the *Nymphæa*, the air that exists in the pneumatic cavities appears, according to Dutrochet, to come in and out of them by the vessels of the footstalk. It seems that this air contains a little less oxygen gas than the atmosphere. Dutrochet makes out that the oxygen contained in the air of plants goes on diminishing from the leaves, where it is in the ratio of 16 per cent., to the roots, where it is only 8 per cent. His experiments have been made on *Nymphæa lutea*.

The tendency of leaves to present their varnished surface to the sky and their pale surface to the earth, though very general, is not altogether without exceptions. Thus, the misletoe presents its leaves in all directions. The *Ruscus aculeatus* and some grasses turn their unvarnished surfaces upwards. It is the most deep-coloured surface that is directed towards the sky; and if it were to the presence of air that they are indebted for their paleness, it is the surface most provided with pneumatic cavities that would be directed towards the earth.

Among naturalists, Bonnet is the first who has examined the phenomenon of the direction of leaves. He has shown that if the position of a leaf be changed, so as to present to the sky its under surface, the leaf turns itself over spontaneously more or less quickly. This turning over is more rapid in young leaves than in old ones,

* I have ascertained that this varnish is produced by a thin coat of wax, or rather myricine soluble in sulphuric ether.

but towards the end of autumn it ceases to manifest itself. As Bonnet believed that the leaves turn themselves over in the dark as well as in the light, he imagined that this phenomenon is the consequence of the under surface of leaves containing fibres liable to contract themselves by humidity, and their upper surface fibres that contract themselves by the influence of heat. He went so far as to construct, in support of his hypothesis, artificial leaves, of which the upper surface was of parchment and the lower of linen, and he states that the heat and the damp produced in them the same motions as in natural leaves. According to him, the dampness of the earth determines the under surface of the leaves to turn themselves on that side, and the heat of the sun acts in the same way on the upper surface. This opinion was the more singular in Bonnet, from his having observed that the leaves turn themselves over in water as well as in the air, and from his believing that this change of position in the two surfaces of leaves is the result of the contortion or the inflection of the footstalk.

Dutrochet indeed attributes to the influence of light the turning over of leaves, but he considers the flat part of the leaf as passive, and the footstalk as the only agent in its motion. He quotes besides no other experiment in proof of the influence of light but those of Bonnet, and especially the one in which some leaves of a cherry-tree, placed under the shadow of a table so as to receive light laterally, put themselves in a vertical position with the end downwards.

He gives for the chief ground of his opinion respecting the action of light in this phenomenon, the fact that having placed a *Convolvulus* in the circumference of a wheel rapidly revolving, the leaves after eighteen hours presented their upper surface to the centre of rotation and their under one to the circumference. He concludes from this experiment that leaves present naturally their upper surface to the light; but, as Decandolle justly observes, it would have been more natural to conclude from it that they present it to gravitation. He recapitulates his opinion in these words:—"I have attempted without success to discover how light acts in determining the torsion of the footstalk when the leaf is turned over. It seems evident that in this circumstance the influence of light is exercised on the flat part of the reversed leaf, and that this influence is transmitted to the footstalk whose contortion it produces; but I do not see here what is the connection between cause and effect. The turning over of a leaf depends on two different causes:—first, the disposition of the footstalk to raise itself towards the sky when it has been accidentally bent towards the earth; secondly, the disposition of the footstalk to bend towards the light, but only when it presents its upper surface to it; the flat part of the leaf is entirely passive."

I know no more recent paper on this subject, which appeared to me to be far from being sufficiently elucidated, and I have therefore endeavoured to add something to what was already known.

I thought it was necessary first to ascertain clearly whether light was really the

agent that caused the turning over of leaves, and afterwards to study the mode of its action on the two surfaces of those organs.

After I had verified most of the experiments of Bonnet on the turning over of the leaves of a great number of plants, as far as relates to the rapidity of the phenomenon, the frequency of its reproduction on the same leaves, &c., in leaving the plants exposed to the light, I placed many plants in such a manner that their inverted leaves remained in complete darkness. Contrary to Bonnet's observations, I found that the leaves in that case did not regularly turn over. It often happened, for instance in a branch of lilac, in a plant of *Polemonium cœruleum*, that the footstalks and the flat part of the leaves so kept in darkness, turn about first in one direction, then in another; but this happened equally to the leaves left in their natural position. This appears to me to be the consequence of the state of uneasiness in which the privation of light puts the leaves; they seem to move about as if in search of this agent, and this cause, as well as the elastic reaction of the footstalk, when drawn from its natural position by torsion, which process I have always avoided, may have led the observer into error.

With the conviction that light is the only agent whose influence causes the turning over of leaves, I made the following experiment. In cold weather (45° Fahr.) I placed a vase of geranium in such a manner that one of its leaves, young, though fully developed, without altering in the least its position or that of the vase, should be entirely covered from the light on its upper surface, by a double screen of black paper that did not touch it, while, on the contrary, the under surface was strongly lighted by a mirror placed below at the proper inclination. Three days after, the flat part of the leaf had begun to turn over; and after six days, the leaf was entirely inverted, so as to present its upper or varnished surface towards the mirror. The apparatus was kept in the same state during a fortnight, and the leaf continued in the same position, the upper surface downwards towards the mirror, and the under upwards towards the screen. The mirror and the screen were then simultaneously removed, and the leaf was left presenting to the diffused light its under surface that was uppermost. After a few days the leaf turned itself over again, and the torsion took place by a motion of the flat part on the point where it is inserted in the footstalk. This experiment has been repeated many times on various plants with the same results, and seems to me conclusive.

When the two surfaces of leaves are exposed to light at the same time, they do not change their position, but seem to suffer; if the under surface be turned towards the mirror, while at the same time the upper surface being shadowed by other leaves, does not receive as large an amount of direct light as the other surface receives of reflected light, the flat part of the leaf contracts itself so as to render it almost globular. The edges of the upper surface are thus presented to the mirror and cover over the under surface.

Some geranium leaves were covered with a screen of black paper attached to their

upper surface by a little gum or a pin. In that case, all the marginal parts of the flat part of the leaf separate themselves from the screen, bend downwards, and the leaf takes a globular form round the point tied to the screen. It succeeds in that manner to expose a part at least of its upper surface to the diffused light below the shade of the screen. When the same experiment is repeated with a mirror placed so as to cast light upon the under surface of the screened leaf, the bending downwards of the marginal portions of the flat part is still more marked and rapid; the mirror giving a stronger light to those parts of the upper surface thus brought to receive it.

When the screen is large enough to allow of no light reaching the upper surface of the leaf, even after the bending of its flat part in a globular form, and no mirror is used to supply the deficiency, the leaf turns yellow and dies.

Light, then, is the direct and indispensable agent in the turning over of inverted leaves, and causing them to assume their natural direction. Its influence is the more rapid, all other circumstances being alike, the greater the difference between the two surfaces of the leaf experimented upon. Thus the leaves of French beans, or of raspberry-bushes, where the two surfaces are of very different colours, turn over completely when inverted, and frequently in less than two hours. In the lilac, where the two surfaces of the leaves are very similar to one another, the turning over is slow and does not seem complete; the flat part of the inverted leaf assuming often a spiral form.

Bonnet and Dutrochet agree in admitting that the turning over of leaves always takes place by a flexion or torsion of the footstalk. The last-named author has even said that a footstalk alone could raise itself erect by the action of light as well as if it were part of a whole leaf. My own observations have convinced me that the flat part of the leaf, or even a separate portion of it, can turn itself over.

In some leaves, for instance in those of the lilac, the *Polemonium cæruleum*, it is always in the flat part alone of the leaf that the motion takes place, and the leaf turns itself into a spiral form to come back by degrees to a regular position. In others, on the contrary, the motion takes place in the footstalk. This is the case in the geranium, the French bean, the raspberry-bush, the horse-chestnut, the plane-tree, the judas-tree, &c. In this latter I have seen the turning over of the leaf take place without any change of position in the footstalk, but by a sort of rotation of the flat part on that portion of the footstalk where it is inserted, and where there is a natural swelling, which swelling was much increased by the change. The footstalk then formed an obtuse angle with the flat part of the leaf, instead of a very acute angle as usual.

In this experiment, as in all the others, the branches had been inflected and tied in a convenient position for the light, but without touching the footstalks, in order to avoid the reaction of torsion.

A vase of geranium, the leaves of which had all directed their upper surfaces towards a window, had been reversed so as to present to the window the under surface of its

leaves. All the young leaves turned themselves over by moving on the footstalk, either bending it downwards or turning it over at its base. Out of the thirteen leaves which had turned themselves over, nine repeated the same process, chiefly by a torsion on the base of the footstalk: the others dried up. On reversing the plant a third time, the leaves did not turn themselves over any more, but became dry. The experiments were made during the autumn, the least favourable season for them; for in the spring the same leaf turns itself over as many as fifteen times. When, therefore, the turning over of most leaves can be freely effected, it takes place in most cases by the motion of the footstalks; but even in plants where it is effected by this means, it can take place in the flat part of the leaf itself. Thus, I placed a geranium leaf, covered with a black paper screen fastened on its upper surface, so as to have it illuminated underneath by means of a mirror. It is evident that if the footstalk had been bent or inflected, the position of the leaf with respect to light could not have been more favourable than it was. The screen would have been placed between the mirror and the upper surface, just as it was between it and the sky; and the light of day would have fallen on the under surface then turned upwards, as the light of the mirror fell. In this dilemma, the flat part of the leaf bent itself downwards, turning from the screen as far as the pin which held it would allow; and the edges, continuing their motion so as to unite below the screen, gave a globular shape to the leaf, and thus exposed a considerable portion of the upper surface to the reflected light, and shaded from it the under surface.

In the same experiment, a young leaf which was accidentally shaded on its upper surface by the screen, though at some distance, bent its footstalk to avoid it. Thus on the same plant, and at the same moment, each leaf took a different, but the most appropriate mode to place itself on the best possible position with regard to the light. The same experiments tried on the *Polemonium cæruleum* gave very similar results.

Many other experiments exhibited the faculty possessed by the flat part of leaves to turn itself over independently of the footstalk. Thus, after having ascertained that, as had been already seen by Bonnet, leaves turn themselves over when immersed in water, just as they do in the air, I placed in a glass full of water some leaves of geranium, French beans, &c., of which the footstalks were passed through a hole bored in a stick, and in such a way as to leave outside the flat part alone of the leaf. When its under surface was presented to the light, the flat part of the leaf turned itself over in curling up. The same thing happened with leaves whose footstalks had been entirely removed, and replaced by a small wooden pin fastened in the hole of the stick to make the flat part of the leaf steady. A leaf deprived of its footstalk and freely suspended in water so as to expose to light its under surface only, had curled itself up and had taken a form somewhat globular, so as to cause a great portion of its upper surface to receive the light.

These experiments seem to show that the flat part of the leaves is far from being passive in their turning over, as Dutrochet had supposed. The turning over takes

place either by the action of the footstalk, or by the motion of the flat part, according as each of these modes will most conduce to the final result. Thus, when I immersed in water an entire branch of geranium so as to expose the under surface of its leaves to the light, all the young leaves turned themselves over in three days by moving on the point of insertion of the flat part of the leaf into the footstalk, and without the curling-up of the leaf. It has been the same when the footstalk has been kept on a leaf fixed in the bored stick, so as to allow the footstalk perfect freedom of motion in placing it in the hole.

I have endeavoured to ascertain whether this action of light on the surface of leaves, which so evidently exists, would be so powerful as to excite in them a real physical attraction or repulsion. With this view I placed on a moveable cork-float some leaves of the raspberry-shrub (*Rubus idæus*), which are among those whose turning over is most energetic. I placed the float on a glass full of water, and arranged the leaves so that their under surface alone was exposed to light, all the other sides of the apparatus being carefully darkened by means of black paper screens. The whole was kept free from all vibration, and an index showed the position of the float by means of a graduated circle. The leaves turned themselves over by a torsion of the footstalk at the point where the flat part is inserted into it, but there was not the least motion in the float.

The same experiment was repeated many times with leaves of French beans, maple (*Acer pseudoplatanus*), clover (*Trifolium pratense*), &c., and gave the same results.

In a leaf of geranium placed under the same circumstances, the turning over took place by a bending of the footstalk, which thus brought down the flat part of the leaf so as to present the upper surface to the light. In reversing the apparatus, and replacing the leaf in an inverted position, the footstalk raised itself up and regained its primitive situation. There was no motion whatever in the float. The same result was obtained with a leaf of *Camellia japonica*.

When the flat part of the leaf was alone the subject of experiment, it curled up without the float changing its position.

When the plant itself was left floating freely in the water, properly counterpoised, the leaves placed in an inverted position with respect to the light turned themselves over by a motion of the footstalks; but the body of the plant itself remained stationary.

It would appear, therefore, that there is neither attraction nor repulsion, in the material and physical meaning of the word, between light and the surface of leaves.

In compound leaves, the turning over sometimes takes place on the common footstalk, as in the raspberry-shrub, and sometimes on the particular footstalk of each leaflet, which turns itself either on the point situated near the insertion of the footstalk to the flat part of the leaf, as in clover, or else on the point of insertion to the common footstalk, as in the horse-chestnut. The removal of one or more leaflets does not prevent the remaining portion turning itself over when placed towards the light in an inverted position.

I wished to ascertain which of the rays of light had the most influential action in producing the turning over of leaves. In order to make absolutely conclusive experiments on this subject, it would have been necessary to operate by means of the rays of light analysed by the prism; but I had not at my disposal the apparatus of a heliostat, &c., which would have been necessary, and had I possessed it, it would probably have been difficult to arrange the experiment properly; I was consequently obliged to confine myself to the use of coloured glasses. But with the view of ascertaining what degree of confidence they deserved, I analysed with a flint-glass prism a ray of light transmitted through each of the coloured glasses I made use of. I could thus easily find out their degree of purity. The following are the results of this trial.

Glass coloured red by protoxide of copper—spectrum perfectly pure.

Glass coloured blue by cobalt—spectrum contains a little red.

Glass coloured green by chrome—spectrum pure contains very little yellow.

Glass coloured yellow by silver—spectrum contains many orange rays.

Glass coloured violet by manganese—a very fine spectrum, but it contains red rays and a few others, chiefly blue.

For the purpose of observing the effect of coloured glasses on the turning over of leaves, I made use of only three colours,—blue, red and violet.

Three leaves of the same size and age, taken from the same geranium, were placed in an inverted position towards the light; the first behind a blue glass, the second behind a red, and the third behind a violet one. In all these experiments, and they were repeated a great many times, the leaves turned themselves over in the violet and blue rays, and remained motionless in the red. The most remarkable effect was in the blue.

It now remained to investigate the influence of light acting on the two surfaces of leaves with relation to the physiological functions of these organs, so important in vegetative life. These functions are chiefly the exhalation and the decomposition of carbonic acid. I propose now to examine the influence of light under these two heads.

§ 4. *Action of Light on Exhalation.*

Every one knows that plants exhale in the atmosphere a large quantity of water, and that this function is chiefly ascribed to the leaves. To these organs, indeed, the exhalation of water, properly so called, seems to belong; the other parts of the plant losing only an infinitely smaller portion of water, apparently the result of the common evaporation which every humid body experiences in the air. Decandolle calls this last-mentioned loss of water *deperdition*, to distinguish it from *exhalation* properly so called.

Senebier has alleged that the vegetative exhalation is nothing, or nearly so, in the dark. This may be true when the temperature is very low and the atmosphere very damp; but I have ascertained, in accordance with Dutrochet's results, that in summer

and in ordinary circumstances, exhalation continues during the night, though in much less quantity than during the day.

I have attempted to determine what difference could be perceived in the exhalation of leaves when the one or the other of their surfaces was exposed to light. I began by ascertaining that, when the leaves of a great many different plants are thus exposed in the air or in the sun's rays at the same temperature, the loss of weight they experienced in the two cases is proportional during the same time; at first, however, rather greater when their under surface is exposed to light than when it is the upper or varnished surface. Thus, in two hours, horse-chestnut leaves lost water in the ratio of 13·6 per cent., when the under surface was exposed to light, to 11·2 per cent. when it was the upper one; with pear-tree leaves, the ratio was 8·45 to 7·75 per cent. But the more the leaf dries up, the quicker the difference diminishes; and when no more real exhalation exists, but there is only deperdition of water, it becomes nothing, and the leaves lose, during an equal time and at the same temperature, a proportional weight of water, whatever be the surface exposed to light.

To ascertain the variations in the exhalation properly so called, I weighed the leaves recently gathered, either with their footstalks only, or with the branch on which they grew; I immersed them afterwards by the footstalk or branch in a bottle filled with water of which the weight had been accurately taken. One of the surfaces of the leaf was then exposed to diffused light and the other covered with a screen. After a given time, I weighed accurately the leaf and the bottle, and the loss gave the amount of exhalation. The same leaf was then inverted and placed in a contrary direction, so that its other surface was exposed to light during a space of time precisely equal to the first. The loss in weight disclosed to me the quantity of the exhaled water. The temperature was carefully observed, though I had ascertained by direct experiment, so far agreeing with Senebier's, that heat had very little influence on the exhalation itself. I could besides reverse many times during the day the experiment on the same leaf, and thus obtain alternately for its two surfaces the same circumstances of heat and light. For leaves that have a great tendency to turn over, those of the raspberry-bush, for instance, it was somewhat difficult to maintain them without contorsion of the flat part of the leaf with their under surface exposed to light. With leaves of this description the experiment on that surface could not be continued above two hours.

I have made numerous experiments on a great many species of leaves, in all temperatures and in all weathers, but it would be tedious to give the particulars of them. I shall only report the general results.

1st. A leaf immersed in water by its footstalk increases at first in weight a little more during the same time, when its under surface is exposed to light than when it is the upper one that is so. This result is the consequence of the absorption being a little greater in the first case; but at the end of the experiments the leaves have pretty nearly the same weight they had at the beginning.

2nd. As soon as sufficient time has elapsed to allow water to penetrate into the leaf, the loss by exhalation is, in all temperatures and in every atmospherical state, much greater when the under surface of leaves is exposed to light than when it is the varnished side. The proportion has varied a little in the experiments, and according to the nature of leaves, but in general the loss has been three times more considerable; for instance in the maple, the horse-chestnut, the pear-tree, the plane, &c. In some cases, the difference has been still greater; but sometimes it has been only double. It is obvious that to this enormous increase of the loss of water, which takes place in the inverted leaves, a loss already so considerable in the ordinary state, is to be mainly attributed the state of uneasiness, followed by withering and death, which is the consequence of this position when it is forced upon them; and we thus see one of the ends of nature in giving them the means of delivering themselves from this evil.

By means of the coloured glasses, I endeavoured to estimate the influence of each of the rays of the spectrum in the production of this phenomenon. Out of a great many series of experiments I shall select only one.

In two hours, a leaf of raspberry-bush, weighing twenty-three grains, placed in 300 grains of water, exhaled, with its under surface exposed to the light, in a temperature of 20° C. (68° F.),—

	grs.
In diffused light	4·3 water.
In the blue rays	6·3 water.
In the yellow rays	2·0 water.
In the green rays	2·0 water.
In the red rays	1·0 water.
In the dark	0·4 water.

This leaf, the next day, during an equal space of time, and in the same temperature, exhaled, with its upper surface exposed to the light,—

	grs.
In diffused light	2·2 water.
Under blue glass	2·8 water.
Under yellow glass	0·5 water.
Under red glass	0·4 water.
In the dark	0·0 water.

In all the experiments the exhalation was greater in the blue rays than in the others, whether it was the upper or the under surface of the leaf that was exposed to the influence of light. The blue rays excite a greater exhalation than the diffused light; but this light has more influence than the other rays. The red is that in which the exhalation is the smallest.

§ 5. *Action of Light on the Decomposition of Carbonic Acid.*

It is known that this phenomenon, which in plants effects the assimilation of carbon, and perhaps also of oxygen gas, takes place only under the influence of the

solar light on the green parts of vegetables. Senebier has advanced that it is independent of the (*cuticle*) green organs, and takes place in the parenchymatous matter. This is true as long as the plant is not disorganized. Thus, for instance, a slice cut in the parenchyma of a leaf of *Rochæa falcata*, weighing ten grains, gave out in the sun, when immersed in water containing carbonic acid in solution, a certain number of bubbles of oxygenated air. The bubbles appeared to form themselves in the exterior cells, and seemed as if they could not disengage themselves without trouble; they remained attached to the fragment, and it was necessary to shake the vessel in order to make them come up. An equal weight of the parenchyma of the *Rochæa* having been pounded, so as to destroy all the cells, was exposed to the sun in an equal quantity of the carbonic acid solution and during the same time. No oxygenated air was produced. The same negative result was obtained when the expressed juice of this leaf was put in the sun with water, although it contained a great deal of the green matter that fell to the bottom of the tube. When I put into the water a slice of the leaf of Rochæa of the same dimensions as the first, but in which the cuticle had remained with a small layer of green matter, although this fragment weighed only five grains, or the half of the preceding one, I saw a regular series of bubbles disengage themselves from the stomata. I could measure in an equal length of time with the two tubes plunged in the same solution of carbonic acid, three times as much oxygenated air from the slice covered by its cuticle than from the one that was not so covered.

The same experiments repeated with a great many other plants gave similar results, and show,—first, that the green chromule alone is not endowed with the property of decomposing carbonic acid, and that this faculty is the consequence of a physiological action of the cells; secondly, that this decomposition is increased by the agency of the vessels and pores that exist on the cuticles of leaves.

In order to appreciate the influence of light on the production of oxygen gas when it acted on one or the other of the surfaces of leaves, I took two leaves of the same plant as equal as possible in weight and surface, and placed them in two similar bell-glasses, inverted over the same weak solution of carbonic acid or over spring-water. One of the leaves was placed in such a manner as to present to the sun its under surface, and the other its upper one. The other side of the bells was covered with black paper. The gases produced were carefully measured after the experiment, and the temperature was noted.

I have made a great many experiments on a great variety of leaves; and without giving the details in this place, I will only add, that when the leaves are in their natural position, that is to say, with their varnished surface exposed to the light, the bubbles of oxygen gas are produced much quicker and in far greater quantity than when the under surface is exposed to light. During the same length of time, two or three times as much gas is formed in the first case as in the second; and the difference is the more marked the longer the experiment is continued, for the produc-

tion of oxygen by the leaf whose under surface is exposed to the sun goes on constantly diminishing.

I devised another rather striking mode of making the same experiment. In one of my trials, I had been surprised to observe that the leaves of *Camellia japonica* did not, when exposed to the sun in spring-water, disengage oxygen gas by their stomata, but that bubbles of this gas went off through the footstalks. I ascertained afterwards that this fact had already been mentioned by Dutrochet. It afforded me the means of showing the difference of the action of light on the two surfaces of the same leaf.

To make this experiment, I place in two large tubes filled with spring-water, two Camellia leaves having an equal surface, and their footstalk directed upwards. One of the leaves has its upper, the other its lower surface exposed to light, and the opposite side is shaded. I leave the apparatus for at least five or six hours in the dark, after which I expose it to the diffused light at the temperature of 20° C. (68° F.); the direct rays of the sun not being necessary to the production of the phenomenon. After twenty minutes of exposure, there appear on the leaf, the upper surface of which is exposed to the light, numerous bubbles of a gas containing 85 to 90 per cent. of oxygen, disengaging themselves from the aërial vessels placed in the centre of the footstalk, and whose apertures are clearly visible. The bubbles are very small, and so numerous and so rapidly emitted, that it is absolutely impossible to count them; they chase one another, and are all gathered up at the top of the tube. Begun at half-past nine in the morning, for instance, the bubbling lasts with the same activity for an hour, after which it ceases. Towards the end, the current of bubbles is a little less rapid; but the smallest number I was able to count at twenty minutes past ten o'clock, was 120 bubbles per minute. In the leaf whose lower surface is exposed to light, the gas begins to disengage itself only after thirty minutes of exposure to light; the current of bubbles is much less rapid, and during the whole time of duration I could always easily count them. The greatest number produced was 145 in a minute; and while the other leaf still gave 120 of them per minute, this one gave only thirty. The bubbles ceased at the same moment in both leaves, and consequently lasted only three quarters of an hour in the leaf whose under surface was illuminated. I was not surprised, therefore, in measuring the quantities of disengaged gases, to find that the leaf of Camellia exposed to light in its natural position had given three times as much oxygen gas as the other whose position was inverted, all other circumstances being similar, and both being plunged in the same liquid. When the apparatus is again placed in darkness, a new accumulation of carbonic acid takes place in the cells of the leaves; and if they remain in it a sufficient time, the disengagement of bubbles of oxygen gas by exposure to light begins again, with the same differences as to time and proportion, according as the leaf is illuminated on its upper or lower surface. I have seen the same leaves producing the same phenomenon for seven or eight days in succession, by keeping them alternately in

the dark and in the light. The rays of the sun are not indispensable; and the experiment, which is easy to perform and pleasing to witness, succeeds very well in diffused light.

I have ascertained that some other leaves, among others those of the *Laurus thymus*, Portugal laurel, &c., give similar results.

In conclusion, I have endeavoured to show:—

1st. That light is the only agent in the turning over of leaves.

2nd. That it does not act by a physical attraction properly so called.

3rd. That the turning over of leaves takes place sometimes by a torsion of the footstalk, sometimes by a curling of the flat part of leaves.

4th. That the blue rays appear to be the most, and the red the least active in effecting the turning over of leaves.

5th. That the exhalation of leaves is much increased when their under surface is exposed to light.

6th. That the decomposition of carbonic acid and the disengagement of oxygen gas are, under the same circumstances, considerably diminished.

XIX. *Microscopical Examination of the Contents of the Hepatic Ducts, with conclusions founded thereon as to the Physiological signification of the Cells of Hepatic Parenchyma, and as to their Anatomical relation to the Radicles of the Hepatic Ducts.* By T. Wharton Jones, *F.R.S.*

Received May 11,—Read May 25, 1848.

1. In the contents of the larger branches of the hepatic duct, there are seen on microscopical examination,—1st, detached columnar epithelium; 2nd, free nuclei, some round, some oval, about $\frac{1}{3000}$th of an inch in diameter; 3rd, minute granules, free or in amorphous flakes, globules of oil, and fragments of cell-walls.

2. In the contents of smaller branches of the hepatic duct, I have repeatedly observed, in addition to the objects just enumerated, cells of a polygonal shape and about $\frac{1}{1100}$th of an inch in diameter, containing round nuclei about $\frac{1}{3000}$th of an inch in diameter, together with minute granules and globules of oil; cells, in short, identical with those of the parenchyma of the same liver, except that for the most part they were paler, on account of the contained granules and oil-globules being fewer and more minute. In some instances the cells were partially broken up*.

3. To assist us in interpreting the observation now related, and in coming to a conclusion therefrom as to the physiological signification of the cells of hepatic parenchyma, and as to their anatomical relation to the radicles of the hepatic duct, it will be useful to examine the contents of the duct of a gland the structure of which is well understood, such as the pancreas, and to compare them with the proper anatomical elements of the same gland.

4. The proper anatomical elements of the pancreas, it is to be called to mind are,—1st, vesicles composed of tunica propria opening into the radicles of the duct; 2nd, the endogenous cells of these vesicles, or the true secretory corpuscles. The endogenous or true secretory corpuscles are round granulous masses, about $\frac{1}{1000}$th of an inch in diameter, containing in their interior a round nucleus about $\frac{1}{3000}$th of an inch in diameter, and either altogether destitute of a cell-wall, or possessed of an imperfectly-formed one.

5. In the contents of the pancreatic duct, there are found on microscopical

* The human liver and the sheep's liver, principally the former, were the subjects of examination. The contents of the duct were taken up for examination by means of a small microscopical forceps passed from the larger branches in the transverse fissure of the liver towards the smaller imbedded in the substance of the organ. In this way I believe the accidental admixture of hepatic cells from a cut surface of the liver, with the contents of the ducts, was effectually guarded against.

examination,—1st, detached columnar epithelium; 2nd, free round nuclei; and 3rd, a quantity of minute granules, free or in amorphous flakes. Of these objects, the columnar epithelium is the same as that of the wall of the duct itself, and has evidently been detached from it; the free nuclei are identical with those of the endogenous corpuscles of the glandular vesicles, and are evidently, together with the minute granules, the fragments of those corpuscles in process of resolution into pancreatic juice.

6. To apply what we have now learned of the nature of the objects contained in matter taken from the pancreatic duct to the elucidation of our subject. It is scarcely necessary, in the first place, to say that the fragments of columnar epithelium found in the matter from the hepatic ducts have been, like the columnar epithelium contained in the matter from the pancreatic duct, detached from the walls of the ducts themselves. Of the free nuclei, the round ones* are identical with those of the cells of hepatic parenchyma, and are, together with the granulous substance, globules of oil and fragments of cell-walls, evidently such as might be supposed to be the remains of broken-up hepatic cells and their contents in process of resolution into bile,—as evidently as the free nuclei and granulous substance found in the matter of the pancreatic duct are the debris of the endogenous corpuscles of the vesicles of the pancreas broken up and in process of resolution into pancreatic juice. The fact of the existence of hepatic cells in the smaller hepatic ducts above enunciated, sufficiently accounts for the presence of their broken-up remains in the ducts.

7. From what has now been stated, I believe I am warranted in concluding that the cells of hepatic parenchyma are the analogues of the endogenous cells or corpuscles of the glandular vesicles of the pancreas and other racemose glands, or of the glandular tubules of tubular glands, and are, like them, being constantly reproduced, cast off, received into the radicles of the ducts, broken up and resolved into the secreted matter.

8. But besides establishing this physiological proposition, the fact of the existence of hepatic cells in the smaller ducts of the liver, throws light on the anatomical relation of the hepatic cells to the radicles of the hepatic ducts,—a point the most essential in the minute anatomy of the liver, but one which has not as yet been decisively determined by direct anatomical demonstration, though different hypothetical explanations of it have been offered.

9. The different hypothetical explanations referred to may be reduced to two heads.

According to the explanations under the one head, the hepatic cells themselves stand in such a relation to the radicles of the biliary ducts that they pour their contents into them, either by opening separately like follicles at all points, or, after coalescing to form tubules, by these tubules opening into cœcal radicles of the biliary ducts.

* The oval nuclei, mentioned in § 1, resemble those of the columnar epithelium cells, and are probably derived from broken-up cells of that structure.

According to the explanations under the other head, the masses of hepatic cells of which the parenchyma of the liver is composed are pervaded by intercellular passages leading directly into ducts, which from having a proper coat are recognisable as such. The hepatic cells, analogous to the endogenous cells of other glands, which form, like an epithelium, the immediate wall of the intercellular passages, become, in the recognisable ducts, superseded by a proper epithelium.

10. Of these hypothetical explanations, it is to be observed, that those under the first head are founded on the assumption that the hepatic cells correspond to glandular vesicles,—for it is glandular vesicles and not endogenous cells which open into ducts either separately or after having coalesced to form tubules,—an assumption already opposed to analogy and altogether unsupported by any fact, but now completely set aside by the facts and arguments which have been adduced in this paper. Whilst the explanations under the first head must thus be rejected, that under the second head, which assumes the hepatic cells to correspond to endogenous cells, and which was first suggested by Professor Henle of Heidelberg as the most probable, has by the same facts and arguments been proved to be correct in principle.

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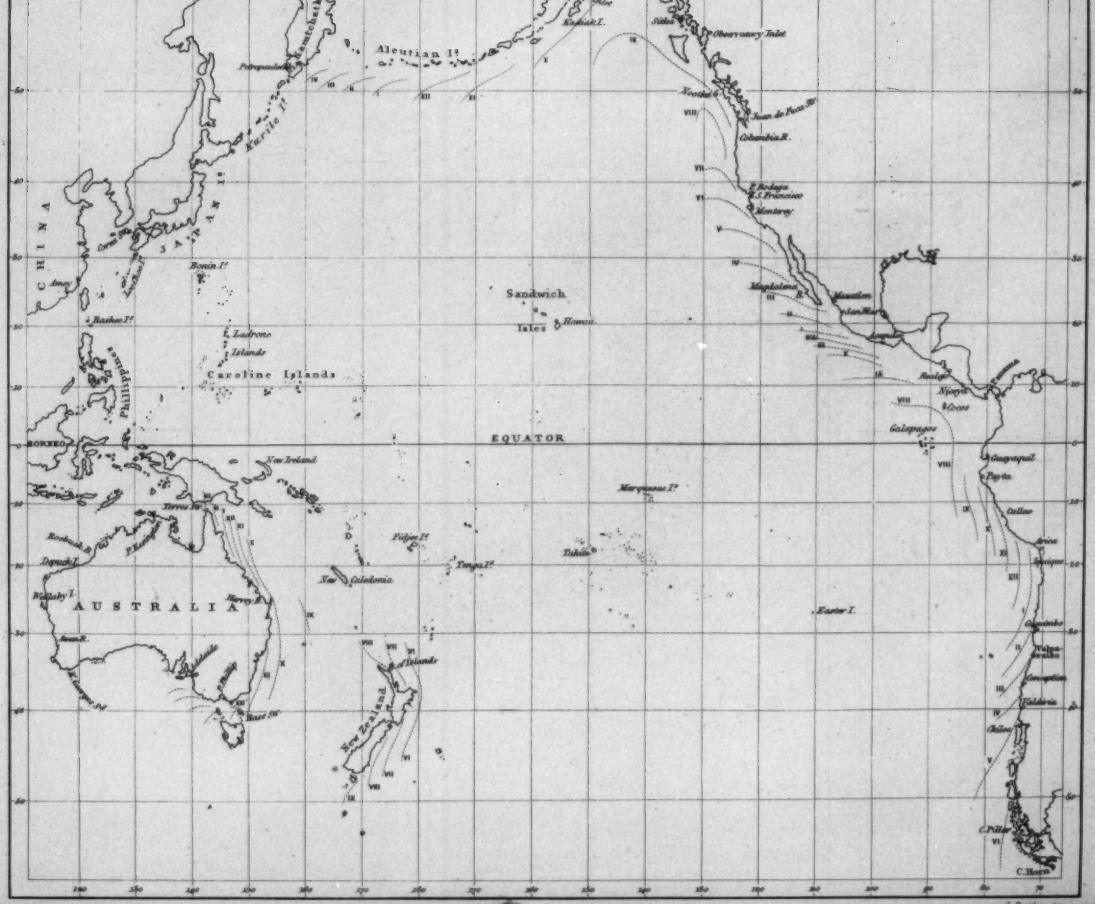
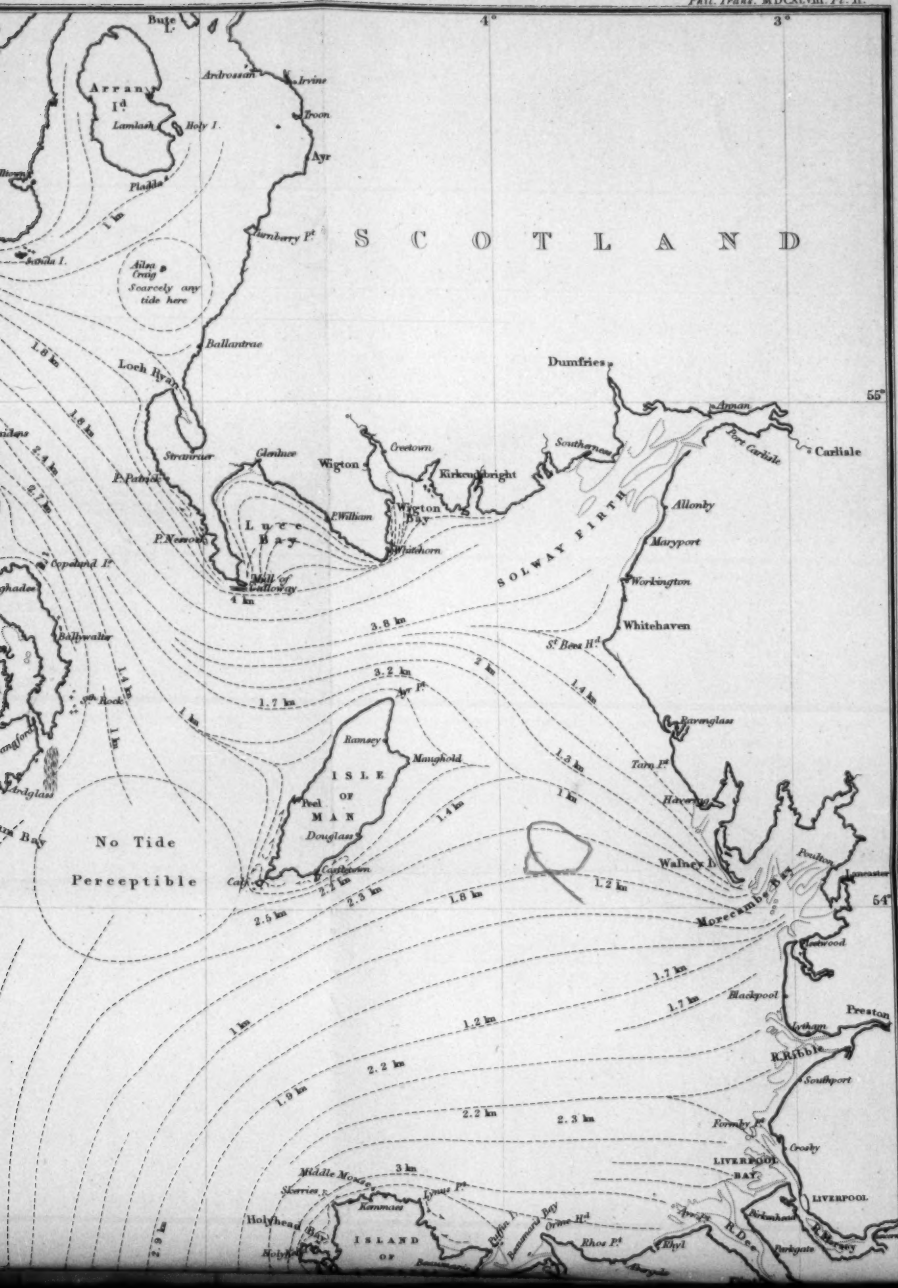
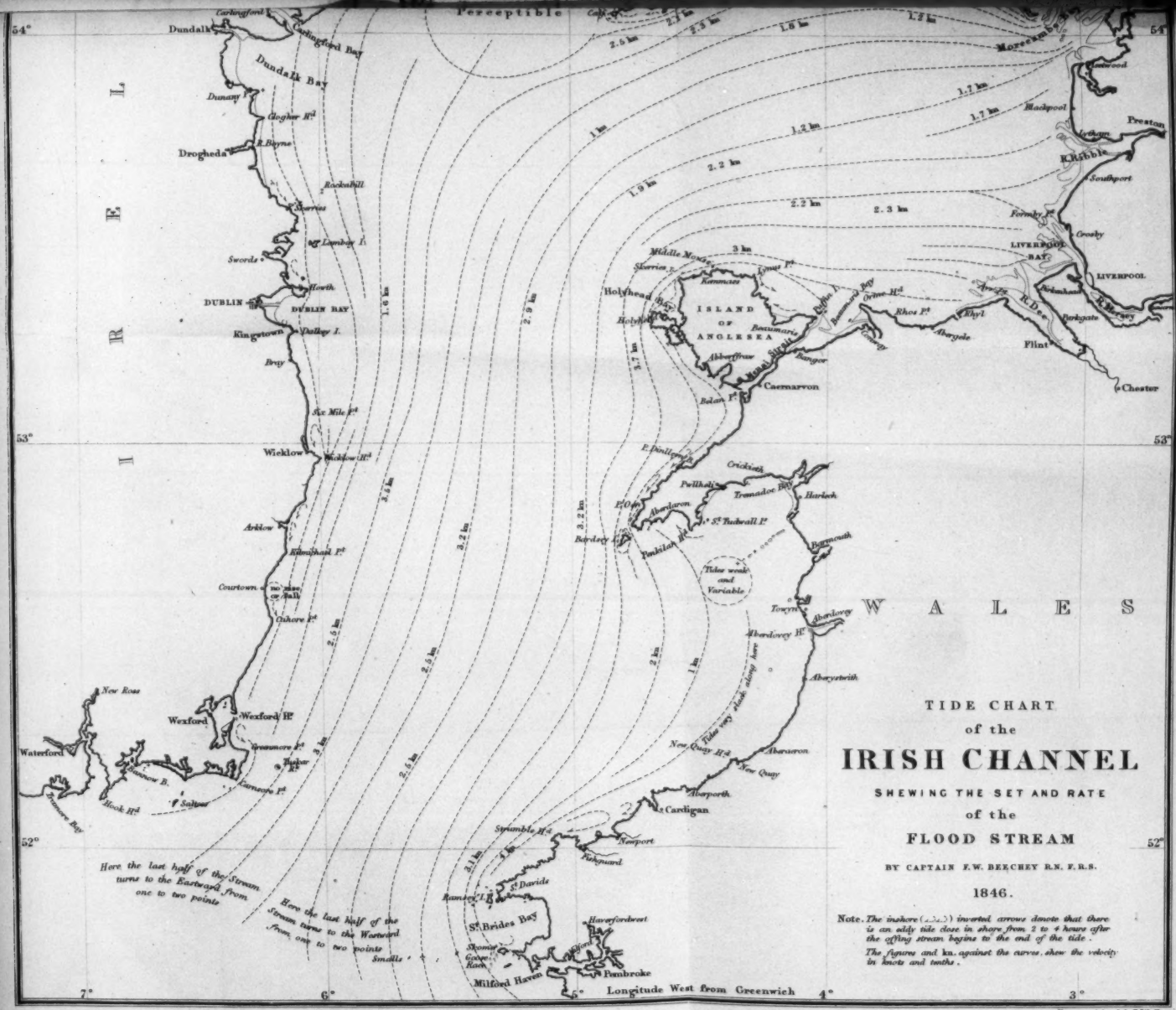


Chart to accompany Dr Whewell's Memoir on the Tides of the Pacific. 1848.

J. Basire, sc.

7°
6°
Isla
L. in Daal
Mull of Oe
Loudhouse Bay
Gigha
Innistrahull I.
Rathlin I.
Giants Causeway
Fair H.d
Innishowen H.d
Rusk
Ballycastle
Cushendun B.
Lough Foyle
Coleraine
Cushendall
55°
Londonderry
Glenarm
Larne
L. Larne
Carrickfergus
Belfast
Lough Strangford
Downpatrick
Dundrum
Newry
Annalong
Carlingford
54°
Dundalk
Carlingford Bay
Dundalk Bay
Dunany P.t
Gogher H.d
R. Boyne
Drogheda
Rockabill
Skerries
Lambay I.
Swords
Howth
DUBLIN
DUBLIN BAY
IRELAND


Bute
Arran
Ardrossan
Irvine
Troon
Ayr
Lamlash
Holy I.
Pladda
Turnberry Pt.
SCOTLAND
Ailsa Craig
Scarcely any tide here
Ballantrae
Loch Ryan
Dumfries
Annan
Port Carlisle
Carliale
Stranraer
Glenluce
Wigton
Creetown
Kirkcudbright
Southerness
P. Patrick
P. William
Wigton Bay
Luce Bay
P. Hamond
Whithorn
Mull of Galloway
SOLWAY FIRTH
Allonby
Maryport
Workington
Whitehaven
St. Bees H.d
Copeland I.s
Ballywalter
Rock
Ramsey
Maughold
ISLE OF MAN
Peel
Douglas
Castletown
Calf
No Tide Perceptible
Ardglass
Barrow
Walney I.
Piel
Lancaster
Morecambe Bay
Fleetwood
Blackpool
Preston
Lytham
R. Ribble
Southport
Formby Pt.
Crosby
LIVERPOOL BAY
LIVERPOOL
Birkenhead
R. Mersey
Parkgate
R. Dee
Ayr Pt.
Rhos Pt.
Rhyl
Orme H.d
Penmaen Bay
Llanddulas
Llanduno
Middle Mouse
Skerries
Ramsey
Holyhead Bay
Holyhead
ISLAND OF ANGLESEY
4°
3°
55°
54°
1 km
1.6 km
2.4 km
3.8 km
3.2 km
1.7 km
1.4 km
1.3 km
2.5 km
2.7 km
2.3 km
1.8 km
1.2 km
2.2 km
1.9 km
2.3 km
3 km



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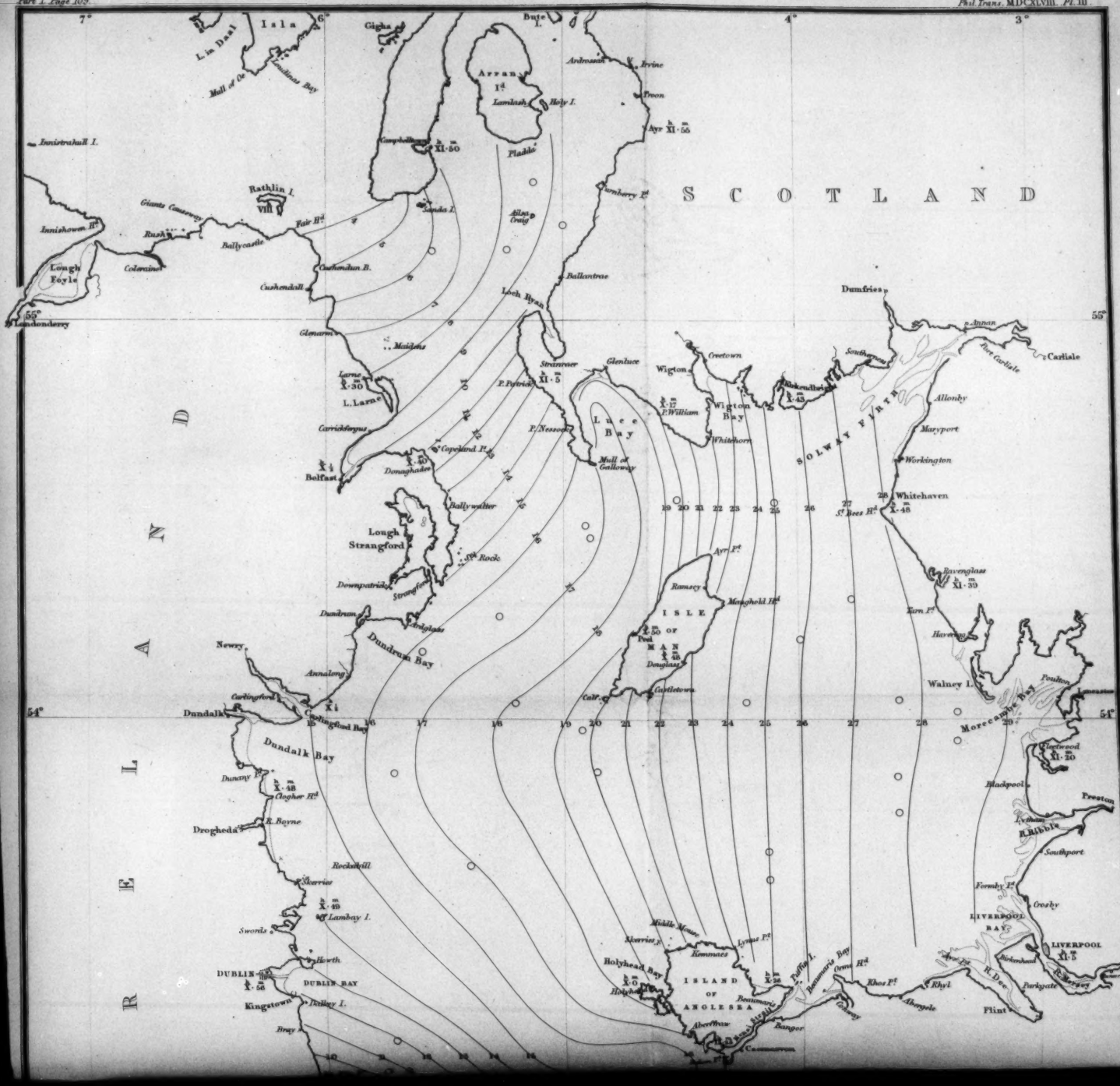
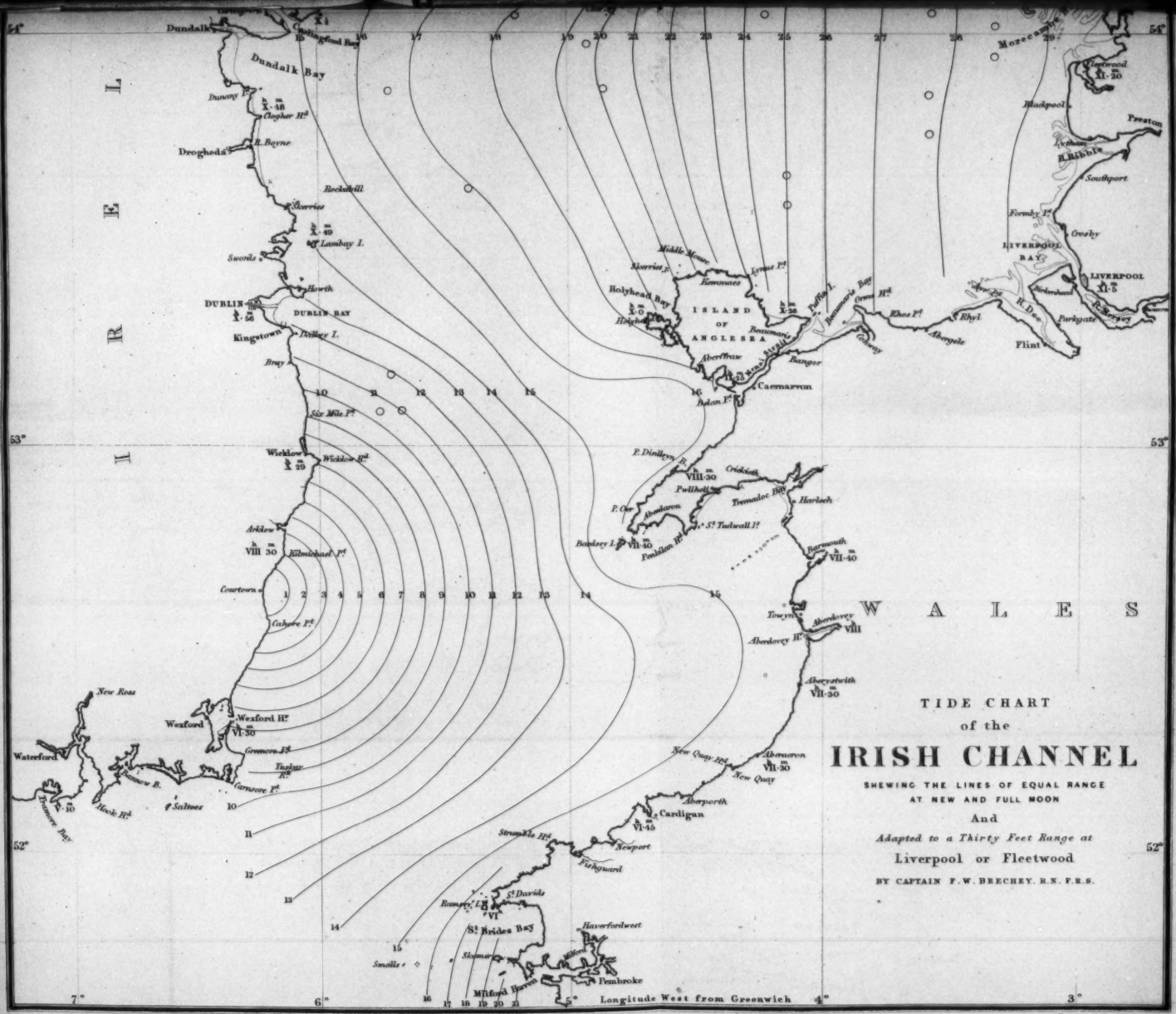
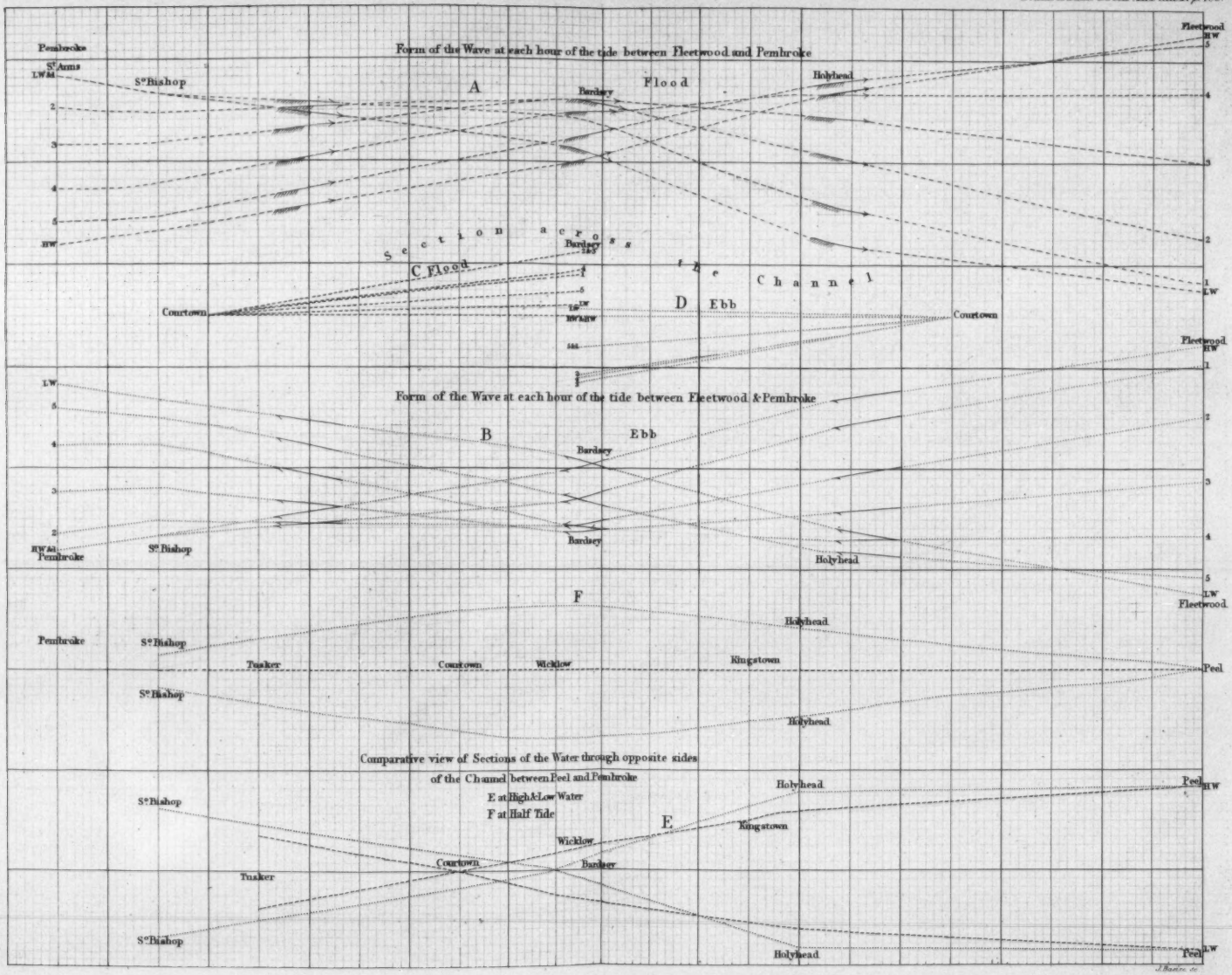
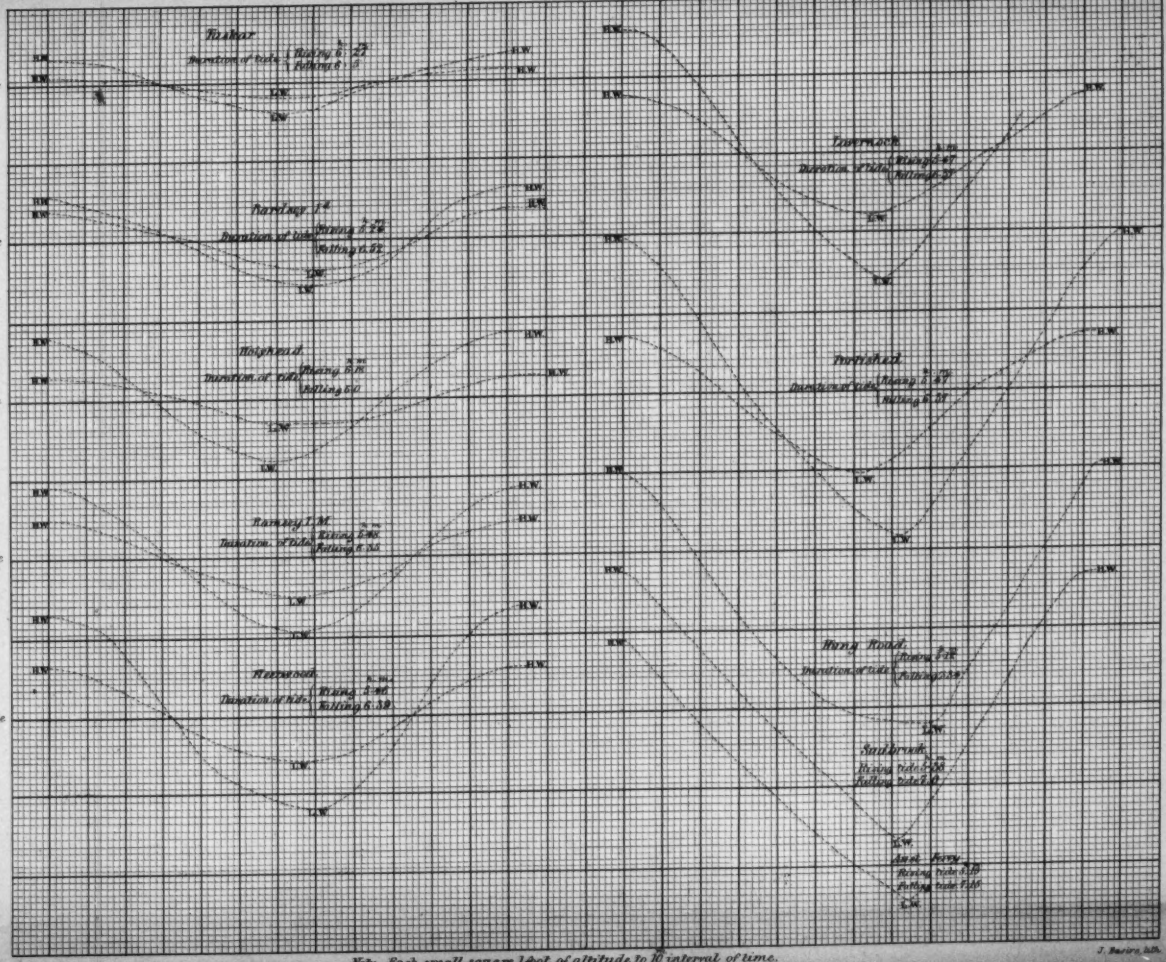

SCOTLAND
IRELAND
Isla
L. in Dead
Mull of Oe
Loudhouse Bay
Gigha
Arran
Lamlash
Holy I.
Ardrossan
Irvine
Troon
Ayr
Ailsa Craig
Pladda
Sanda I.
Campbeltown
Rathlin I.
Giants Causeway
Innishowen H.d
Ballycastle
Fair H.d
Cushendun B.
Cushendall
Colraine
Lough Foyle
Londonderry
Glenarm
Maidens
Larne
L. Larne
Carrickfergus
Belfast
Donaghadee
Copeland I.
Ballywalter
Lough Strangford
Rock
Strangford
Downpatrick
Dundrum
Dundrum Bay
Newry
Annaleng
Carlingford
Carlingford Bay
Dundalk
Dundalk Bay
Dunany P.t
Clogher H.d
R. Boyne
Drogheda
Rockabill
Skerries
Lambay I.
Swords
Howth
DUBLIN
DUBLIN BAY
Kingstown
Dalkey I.
Bray
Ballantrae
Loch Ryan
Stranraer
P. Patrick
P. Nessock
Glenluce
Luce Bay
Mull of Galloway
Wigton
Cretown
P. William
Wigton Bay
Whithorn
Kirkcudbright
Dumfries
Annan
Port Carlisle
Carlisle
Southerness
SOLWAY FYRTH
Allonby
Maryport
Workington
Whitehaven
St Bees H.d
Ramsey
Maughold H.d
Ayr P.t
ISLE OF MAN
Peel
Douglas
Castletown
Calf
Ravenglass
Barrow
Walney I.
Poulton
Morecambe Bay
Fleetwood
Blackpool
Preston
Ribble
Southport
Formby P.t
Crosby
LIVERPOOL BAY
LIVERPOOL
Parkgate
R. Mersey
R. Dee
Flint
Rhyl
Abergele
Conway
Bangor
Aberffraw
Holyhead
Bolyhead Bay
Middle Mouse
Skerries
Lynas P.t
Penmaris Bay
Penmon
Beaumaris
ISLAND OF ANGLESEA
Puffin I.
Khoes P.t
Conway H.d
Ayr P.t
Pickenham
54°
55°
7°
6°
5°
4°
3°


TIDE CHART
of the
IRISH CHANNEL
SHEWING THE LINES OF EQUAL RANGE
AT NEW AND FULL MOON
And
Adapted to a Thirty Feet Range at
Liverpool or Fleetwood
BY CAPTAIN F.W. BEECHEY. R.N. F.R.S.
IRELAND
WALES
ISLAND OF ANGLESEA
Dundalk
Dundalk Bay
Drogheda
R. Boyne
Rockabill
Skerries
Lambay I.
Swords
DUBLIN
DUBLIN BAY
Kingstown
Dalkey I.
Bray
Six Mile Pt.
Wicklow
Wicklow Hd.
Arklow
Kilmichael Pt.
Courtown
Cohore Pt.
New Ross
Wexford
Wexford Hr.
Waterford
Hook Hd.
Saltees
Tuskar
Carnsore Pt.
Longitude West from Greenwich
Engraved by J.& C. Walker.


Form of the Wave at each hour of the tide between Fleetwood and Pembroke
A
Flood
Pembroke
St Anns
LW 6h
St Bishop
Bardsey
Holyhead
Fleetwood
HW
LW
Section across the Channel
C Flood
D Ebb
Courtown
Form of the Wave at each hour of the tide between Fleetwood & Pembroke
B
Ebb
Tusker
Wicklow
Kingstown
Peel
Comparative view of Sections of the Water through opposite sides
of the Channel between Peel and Pembroke
E at High & Low Water
F at Half Tide
E
F

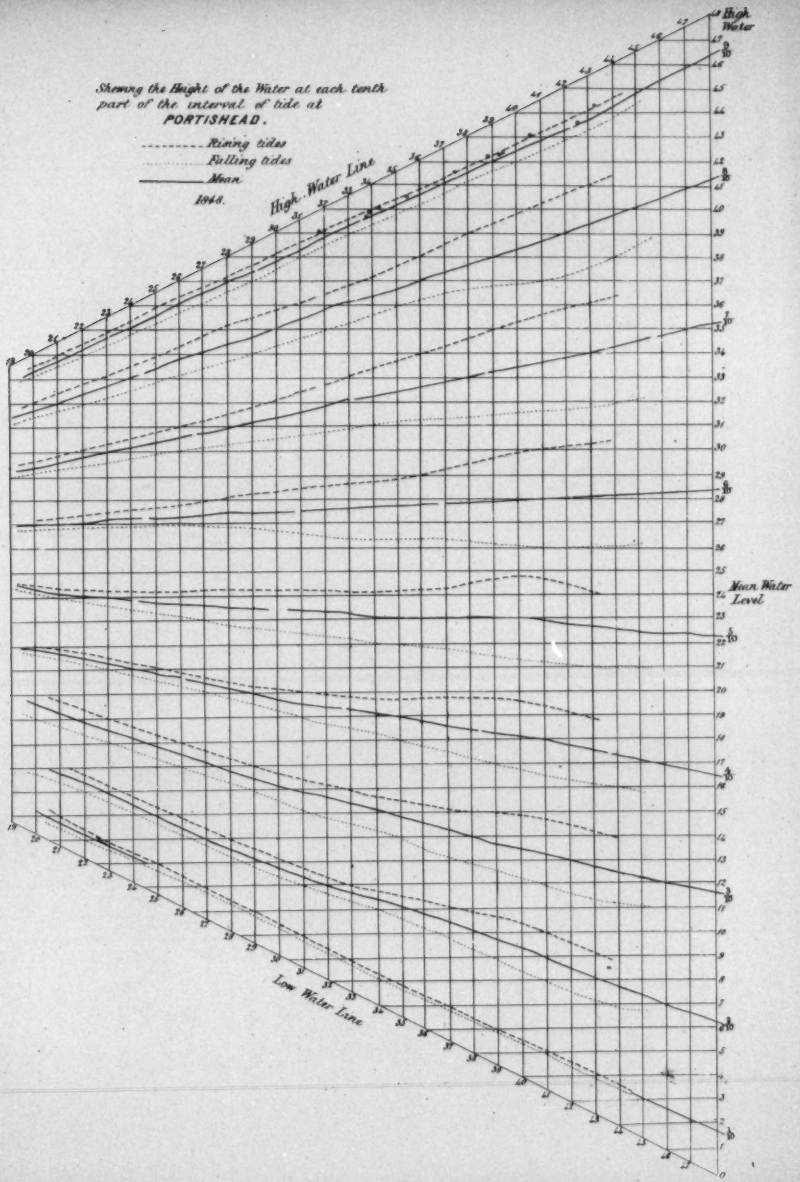
shewing the curve of the Tide Wave at springs and neaps in the Bristol Channel and Irish Sea.

Phil. Trans. MDCCCXVIII. Plate V. p. 112.



Note. Each small square 1 pot of altitude to 10 interval of time.

J. Basire, Sc.


Shewing the Height of the Water at each tenth part of the interval of tide at
PORTISHEAD.
Rising tides
Falling tides
Mean
1848.
High Water Line
Low Water Line
High Water
Mean Water Level

To adapt Soundings taken at any time in the Irish Sea to the low water depths upon the Admiralty Charts.

Phil. Trans. MDCCCXLVIII. Plate VII. p. 110.

Table C.

Table A.

Time from High Water	
h. m.	
0 00	
0 10	
0 20	
0 30	
0 40	
0 50	
1 00	
1 10	
1 20	
1 30	
1 40	
1 50	
2 00	
2 10	
2 20	
2 30	
2 40	
2 50	
3 00	
3 10	
3 20	
3 30	
3 40	
3 50	
4 00	
4 10	
4 20	
4 30	
4 40	
4 50	
5 00	
5 10	
5 20	
5 30	
5 40	
5 50	
6 00	

Table C.

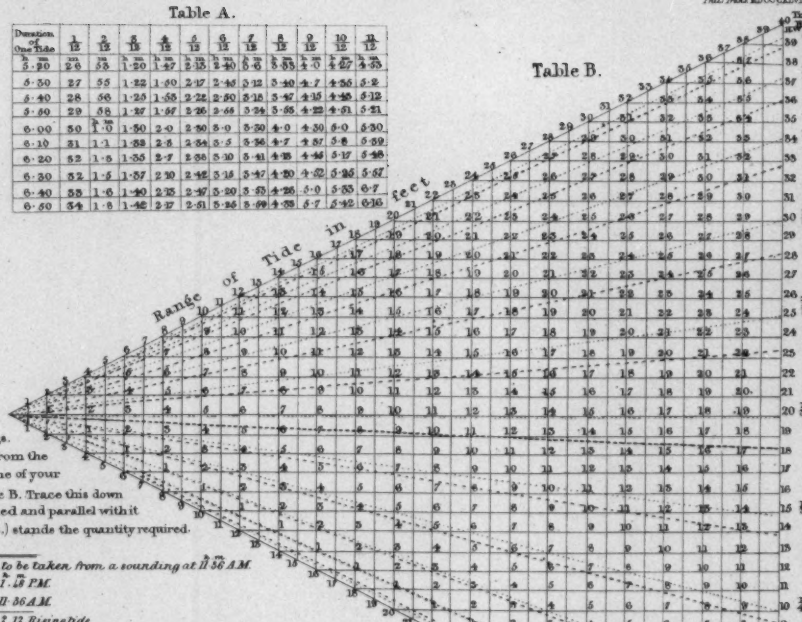
Names of Places.	Range at Springs	Names of Places.	Range at Springs
	feet.		feet.
Liverpool	30	Killmore	11
Holyhead	20	Loughbar	8
Fleetwood	28	Dunmore	15
Pembroke	22	Ramsey I.M.	22
Kingstown	13	King Will.m Bank	23½
Belfast	11½	Ravenglass	25
Bray	10	Whitehaven	25
Wicklow	8	Donaghadee	15½
Arklow	3	Bardsey Isd.	16
Cahore	3	Tusker	9
Blackwater	6	Calf	16½
Wexford	3½	Peel. I.M.	16
Carnsore	8		

For other Places in the Irish Sea, see the Tidal Chart Curves.

Table A.

Duration of One Tide	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12	9/12	10/12	11/12
h. m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.
5·30	2·6	5·3	1·20	1·27	2·15	3·40	5·6	5·55	4·10	4·27	4·35
5·30	27	55	1·22	1·40	2·17	3·46	5·12	5·40	4·7	4·36	5·2
5·40	28	56	1·25	1·58	2·22	3·50	5·18	5·42	4·15	4·46	5·12
5·50	29	58	1·27	1·57	2·26	3·56	5·24	5·35	4·22	4·51	5·21
6·00	30	1·0	1·30	2·0	2·30	3·0	5·30	4·0	4·30	5·0	5·30
6·10	31	1·1	1·32	2·3	2·34	3·5	5·36	4·7	4·37	5·8	5·39
6·20	32	1·5	1·35	2·7	2·38	3·10	5·41	4·15	4·46	5·17	5·48
6·30	32	1·5	1·37	2·10	2·42	3·16	5·47	4·20	4·52	5·26	5·57
6·40	33	1·6	1·40	2·13	2·47	3·20	5·53	4·26	5·0	5·35	6·7
6·50	34	1·8	1·42	2·17	2·51	3·26	5·59	4·33	5·7	5·42	6·16

Table B.



To reduce Soundings roughly to low water springs.
Find the range for the day in the "tide tables."* From the time of high water at your station take the time of your sounding and seek a corresponding time in table B. Trace this down to the line of range for the day above mentioned and parallel with it under the range at springs for the place (table C.) stands the quantity required.

EXAMPLE.

Sept. 20th 1846 off Liverpool. Require the quantity to be taken from a sounding at 11h 36m A.M.

Range for the 20th Sept. 24 feet — *High Water* 1h 48m P.M. — *Time of sounding* 11 36 A.M. — *difference* 2 12 *Rising tide*

In table B. under 24 feet range and 2h 12m and parallel with it under the spring range 30 feet stands 19m 8s the quantity required.

To reduce the Soundings accurately. (1.) Take from the "Tide Tables" on the given day the high water preceding and following the time of your sounding and subtract them, half this difference call the Duration of Tide. (2.) Subtract your time from the nearest of these times of high water. (3.) Find from the tide tables the "Range for the day." (4.) In table A. seek a duration of tide equal to yours above found, and opposite it the time of your sounding from high water, note the proportional part at the head of the column. (5.) Enter Table B with this proportional part in the right hand column, and proceed as directed below to trace the nearest dotted line to the intersection with the line of range for the day and parallel with it under the spring range stands the quantity required.

EXAMPLE. Sept. 20th 1846. off Liverpool. Required the quantity to be taken from a sounding at 4h P.M.

High Water at Liverpool 20th Sept. 1. 48 P.M. — High Water 1. 48 P.M. — Range 24 feet
D° D° 21. " 2 25 A.M. — Time of east 4. 00 P.M.
2 12 Falling tide.
Duration of tide 5 49

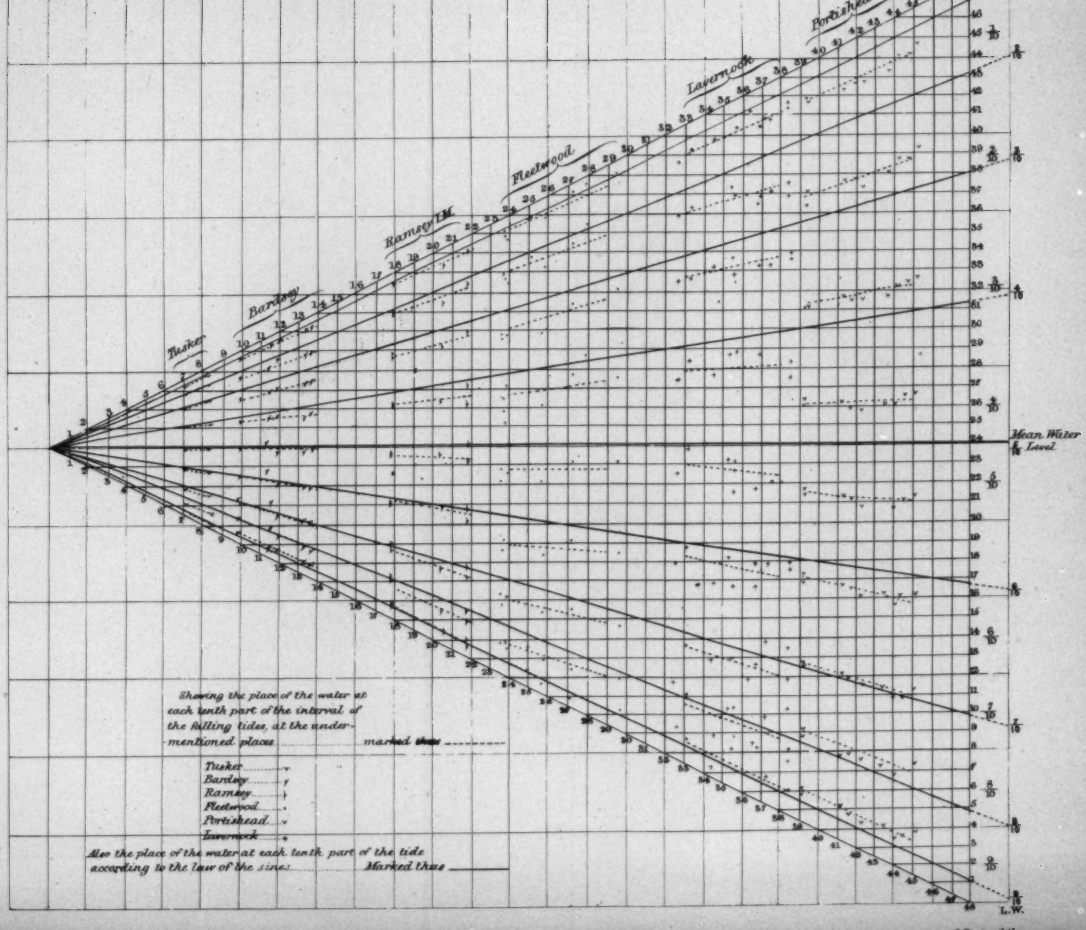
In table A. opposite 5h 49m 2h 12m falls about half way between 1/12 and 2/12 at the head of the column. In table B. under 24 feet range of tide and half way between 1/12 and 2/12 and parallel with it under the spring range (from table C.) 30 feet stands 18m 8s the quantity to be taken from the sounding.

* Knowing the range for the day at Liverpool, the range for the day at any other place in the Irish Sea may be obtained approximately by the following rule.
As 30 feet, is to the range marked upon the Tide Chart, so is the range for the day at Liverpool, to the range for the day at the place of observation.

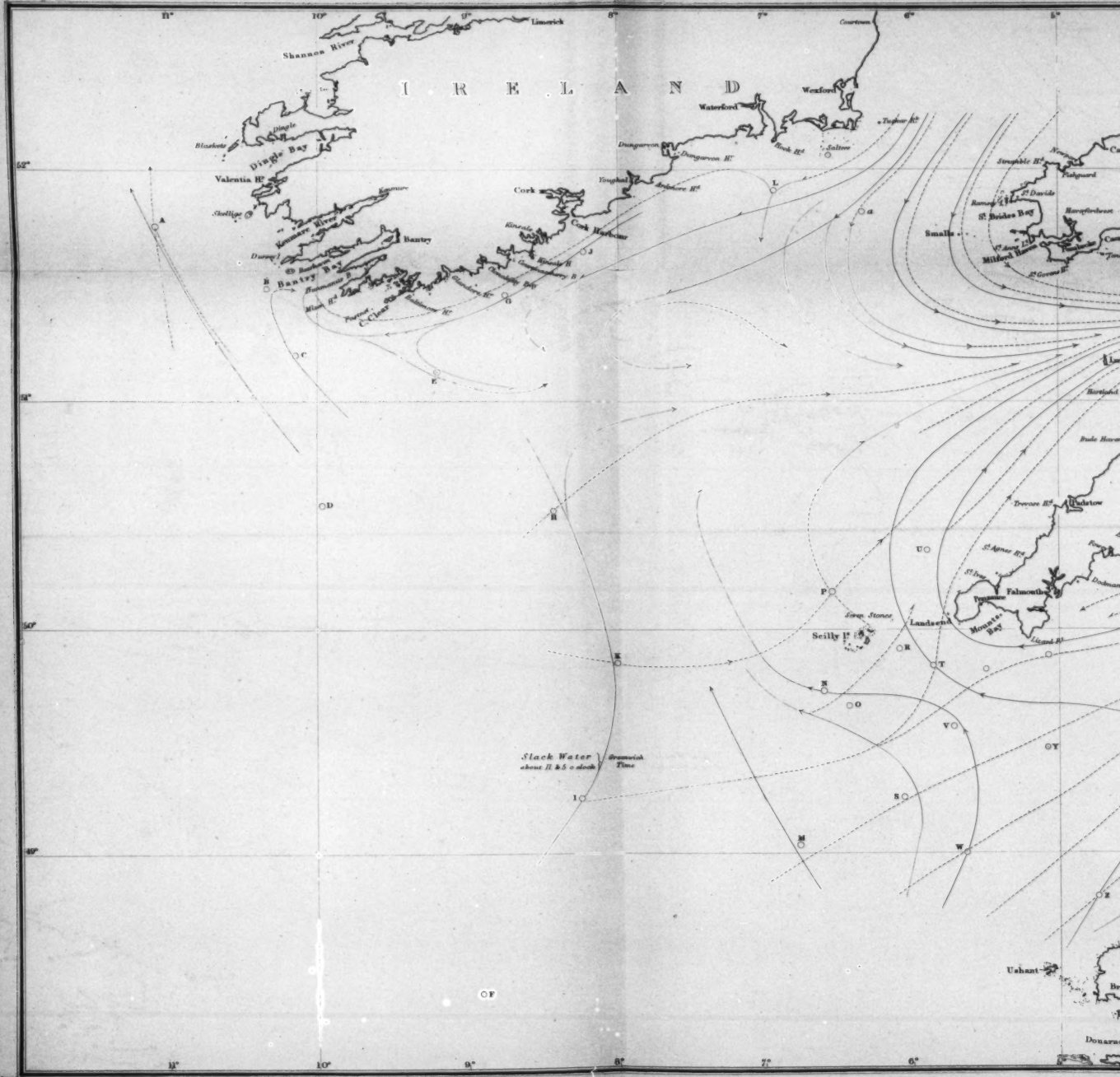
EXAMPLE. Required the range for the day at Bardsey on the 8th September 1847. as 30 : 9 :: 22.

30) 198 (6 6/10 *range for the day at Bardsey.*

N.B. If the tide be falling use the strong dotted lines with the proportional part.
If the tide be rising use the light lines with the prop.l part.


Tusket
Barclay
Ramsey
Fleetwood
Lavernock
Portishead
Mean Water Level
L.W.
Shewing the place of the water at each tenth part of the interval of the falling tides, at the undermentioned places ..... marked thus .....
Tusket .....
Barclay .....
Ramsey .....
Fleetwood .....
Portishead .....
Lavernock .....
Also the place of the water at each tenth part of the tide according to the law of the sines ..... Marked thus _____

J. Bastre. lith.


IRELAND
Limerick
Shannon River
Dingle
Dingle Bay
Blaskets
Valentia Hr.
Skellige
Kenmare River
Bantry
Bantry Bay
Dursey I.
Cork
Cork Harbour
Youghal
Dungarvon
Dungarvon Hr.
Waterford
Wexford
Courtown
Tuskar Ht.
Saltee
Ballycotton Bay
Ballycotton Hr.
Clear
Fastnet
Mizen Ht.
Crookhaven
Glandore Hr.
Rosscarbery B.
Kinsale
Kinsale Hr.
Ardmore Ht.
Black Ht.
Smalls
St. Brides Bay
St. David's
Milford Haven
Fishguard
Strumble Ht.
Trevose Ht.
Padstow
Falmouth
Penzance
Mounts Bay
Landsend
Seven Stones
Scilly I.
Lizard Pt.
St. Agnes Ht.
Ushant
Slack Water about 11 & 5 o clock
Greenwich Time
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
R
S
T
U
V
W
Y
Z
a
b
11°
10°
9°
8°
7°
6°
5°
52°
51°
50°
49°

TIDE CHART
of the
ENGLISH, IRISH AND BRISTOL CHANNELS

SHEWING THE SET OF THE STREAMS
in each
AT THE SAME INSTANTS OF TIME
of the OUTGOING tide

BY CAPTAIN F.W. BEECHEY R.N. F.R.S.

1848.

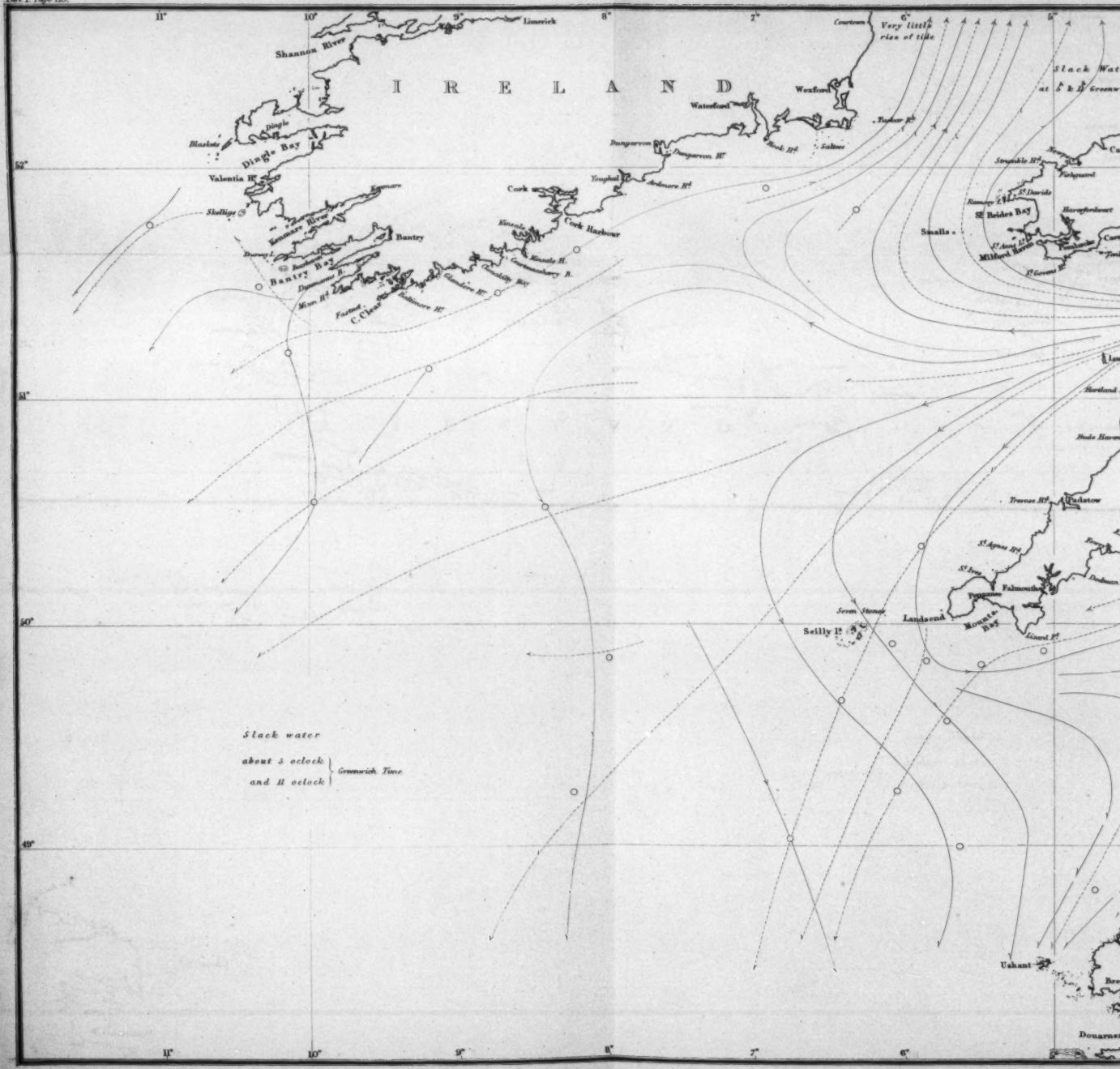
Course of the Stream at { At 11 O'Clock — Slack Water; 1 ←; 3 ←; 5 — Slack Water } On the Days of Syzygy and at Greenwich time

Slack Water about 11 h 50 o'clock Greenwich Time

WALES
ENGLAND
FRANCE

Cardigan · Aberdovey Hd · Aberystwith · Aberavon · Swansea · Mumbles · Tenby · Caermarthen Bay · Hubberstone · Aberafon · Newport · Chepstow · Cardiff · Nash Lt · R. Severn · Bristol · Flatholm · Burnham · Minehead · Watchet · Bridgewater · Lundy I · Morte Pt · Ilfracombe · Barnstaple · Bideford · Hartland · Hanois · Tor Bay · Dartmouth · Berry Hd · Plymouth · Eddystone · Salcombe · Start Pt · Prawle Pt · Torbay · Teignmouth · Sidmouth · Exmouth · Orcombe Pt · Bridport · Portland · Swanage · Old Harry Pt · Needles · Isle of Wight · Spithead · Selsea Bill · Worthing · Brighton · Shoreham · Beachy Hd · Rye · Dungeness · Folkestone · Dover · Deal · Goodwin Sands · Ramsgate · North Foreland · Margate · Horse Bay · Chatham · Sheerness · Gravesend · Greenwich · Woolwich · LONDON · R. Thames · Southend · Maldon · Harwich · Ipswich · Aldborough · Orfordness · Southwold · Lowestoft · Yarmouth · Ostend · Dunkerque · Calais · C. Grisnez · Boulogne · C. Alprech · Touquet Pt · Etaples · R. Authie · R. Somme · Tregnier · Dieppe · St Valery · A. Mills Pt · Penneys · C. Antifer · C. la Hève · Havre · R. Seine · Seine R · Rouen · Honfleur · Trouville · Cabourg · Ouistreham · Courseulles · Port en Bessin · C. Champ · Grandcamp · C. la Hague · Cherbourg · C. Barfleur · Casquets · Alderney · Guernsey · Sarck · C. Carteret · St Germain · Jersey · DD · Rocher Douvre · Minquiers · Chaussey Lt · Granville · Mt St Michel Bay · St Malo · C. Frehel · St Brieux · Morlaix · Roscoff · Harnesses B · Brest · Iles Bas Lt · Lezardrieux · Paimpol · St Brieuc · Sept Lts · Heaux Lt · Iles Bas · Meridian of Greenwich

Engraved by J. & C. Walker.


IRELAND
Shannon River
Limerick
Dingle Bay
Dingle
Blaskets
Valentia Hr.
Shelligs
Kenmare
Kenmare River
Bantry
Bantry Bay
Dursey I.
Dunmanus B.
Mizen Hd.
Fastnet
C. Clear
Baltimore Hr.
Glandore Hr.
Courtmacsherry B.
Kinsale H.
Cork
Cork Harbour
Youghal
Ardmore Hd.
Dungarvon
Dungarvon Hr.
Waterford
Wexford
Courtown
Very little rise of tide
Tuskar Rk.
Slack Water at 5 h. 11 Greenw.
Strumble Hd.
Fishguard
Ramsey I.
St Davids
St Brides Bay
Skalls
Haverfordwest
Milford Haven
St Govans Hd.
Hartland
Padstow
Trevose Hd.
St Agnes Hd.
St Ives
Falmouth
Penzance
Seven Stones
Scilly Is.
Landsend
Mounts Bay
Lizard Pt.
Ushant
Douarnez
Slack water about 5 oclock and 11 oclock } Greenwich Time
11°
10°
9°
8°
7°
6°
5°
52°
51°
50°
49°

TIDE CHART
of the
ENGLISH, IRISH AND BRISTOL CHANNELS
SHEWING THE SET OF THE STREAMS
in each
AT THE SAME INSTANTS OF TIME
of the INGOING tide
BY CAPTAIN F.W. BEECHEY R.N. F.R.S.
1848.

Course of the Stream at { 7 ← Slack Water / 2 ← / 5 ← Slack Water } On the Days of Syzygy and at Greenwich time.

WALES
ENGLAND
FRANCE
LONDON
Cardigan
Aberystwith
Aberaeron
Aberdovey
Barmouth
Pwllheli
Holyhead
Liverpool
Chester
Newport
Cardiff
Bristol
R. Severn
Swansea
Milford
Tenby
Ilfracombe
Lundy I.
Hartland Pt.
Bideford
Barnstaple
Minehead
Watchet
Burnham
Bridgewater
Flatholm
Portland
Weymouth
Portsmouth
Southampton
Spithead
Isle of Wight
Needles
Beachy Hd.
Hastings
Rye
Dungeness
Folkestone
Deal
Goodwin Sands
Margate
Ramsgate
Sheerness
Chatham
Gravesend
Greenwich
Woolwich
R. Thames
Maldon
Harwich
Ipswich
Aldborough
Oxfordness
Lowestoft
Yarmouth
Calais
C. Grisnez
Boulogne
C. Alprech
Tonquet Pt.
Hauples
R. Authie
R. Somme
Cayeux
Dieppe
St Valery
C. Antifer
Fecamp
Havre
C. la Hève
Seine R.
Rouen
Honfleur
Caudebec
Quillebeuf
Pointe Barfleur
C. la Hague
Cherbourg
Casquets
Alderney
Guernsey
Sark
Jersey
C. Carteret
St Germain
Granville
Mt St Michel Bay
St Malo
C. Fréhel
St Brieux
Paimpol
Lezardieux
Morlaix
Roscoff
Brest
Ushant
Iles de Bas
Minquiers
Ouessy Pt
Roches Douvres
Hanois Pt
Sept Iles
Pte de Bréhat
Slack Water about 5 & 11 o'clock Greenwich Time
Meridian of Greenwich
Engraved by J.B.C. Walker

SKETCH

of the Course of the 7 o'Clock stream of Tide

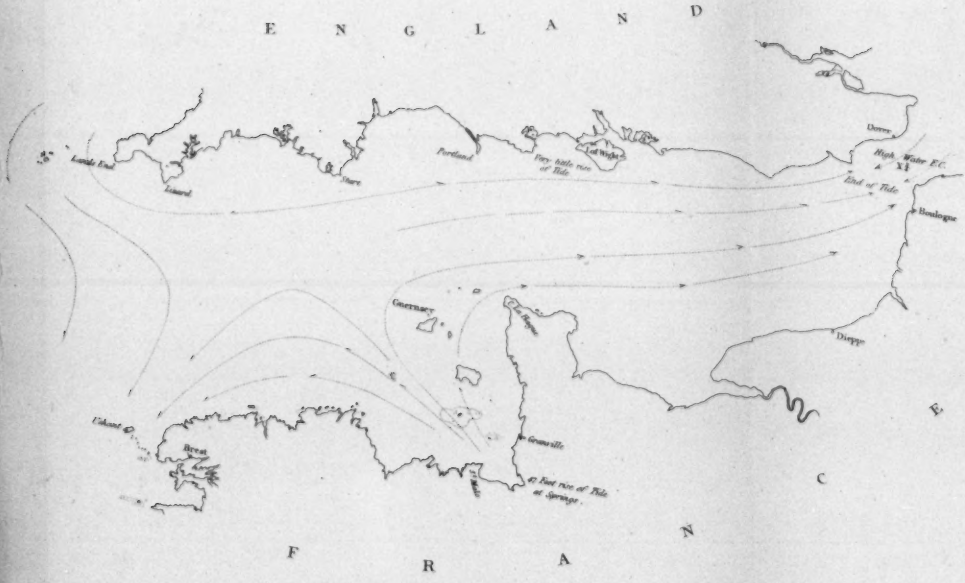
in the

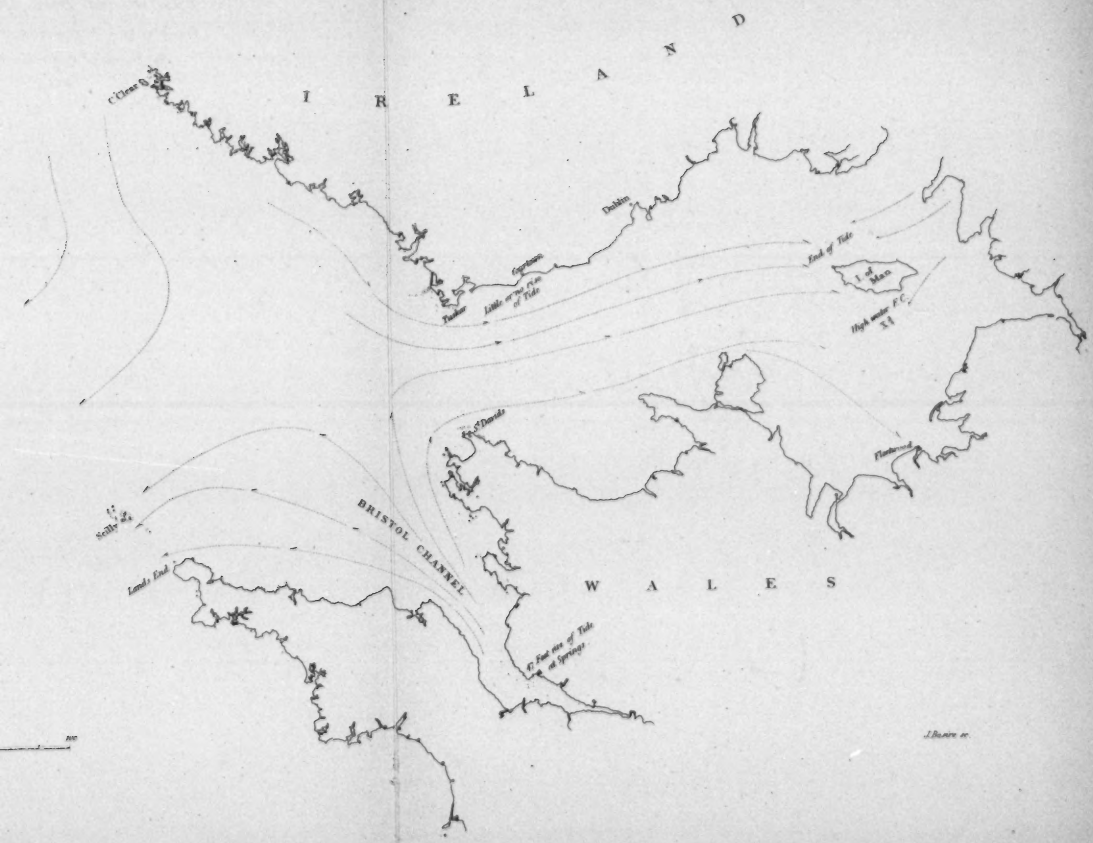
English and Irish Channels.

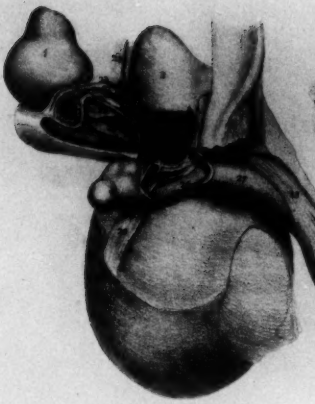
To accompany a letter to the Hydrographer

By Captain F.W. Beechey R.N.

1848.




I R E L A N D
W A L E S
BRISTOL CHANNEL
Dublin
Holyhead
I. of Man
Land's End
Scilly Is.
Tenby
Pembroke
Fishguard
St. Davids
Head of Tide
High water F.C. 2 1
Little or no Flow of Tide
Flow of Tide at Springs



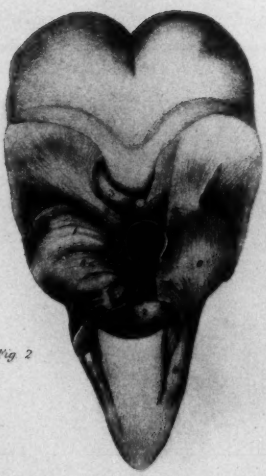
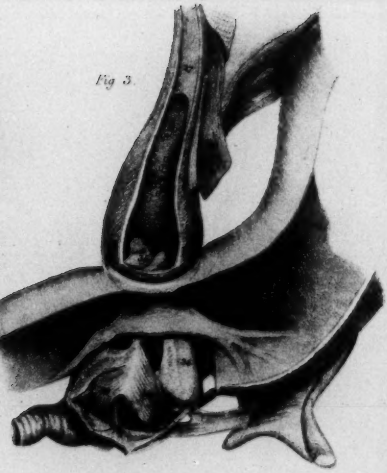


Fig. 2

Maguire lith.

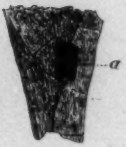
Fig. 2.

Fig. 3.

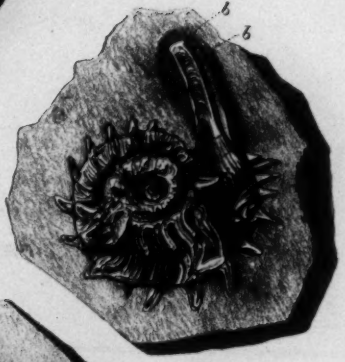


I

I[a]



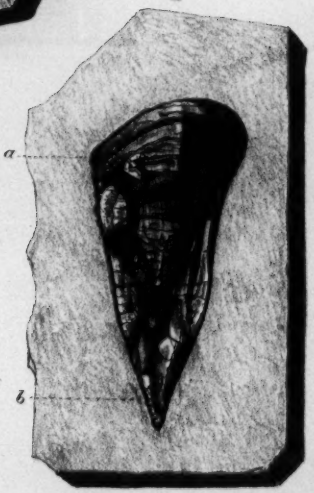
V



III

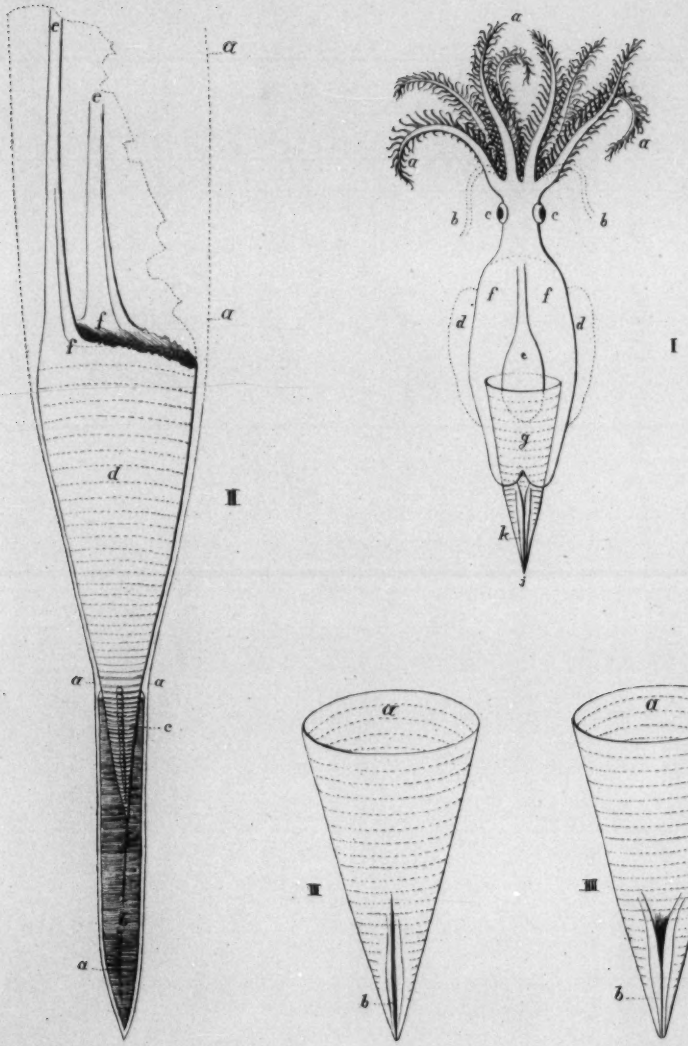
II

III



Dinkel del. et lith.

Printed by J. Basire.



Dinkel del et lith.

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Dinkel del. et lith.

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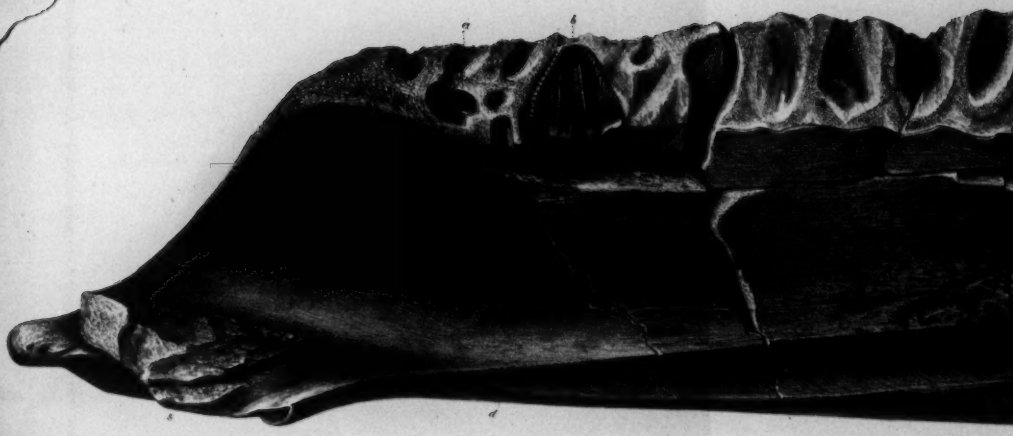


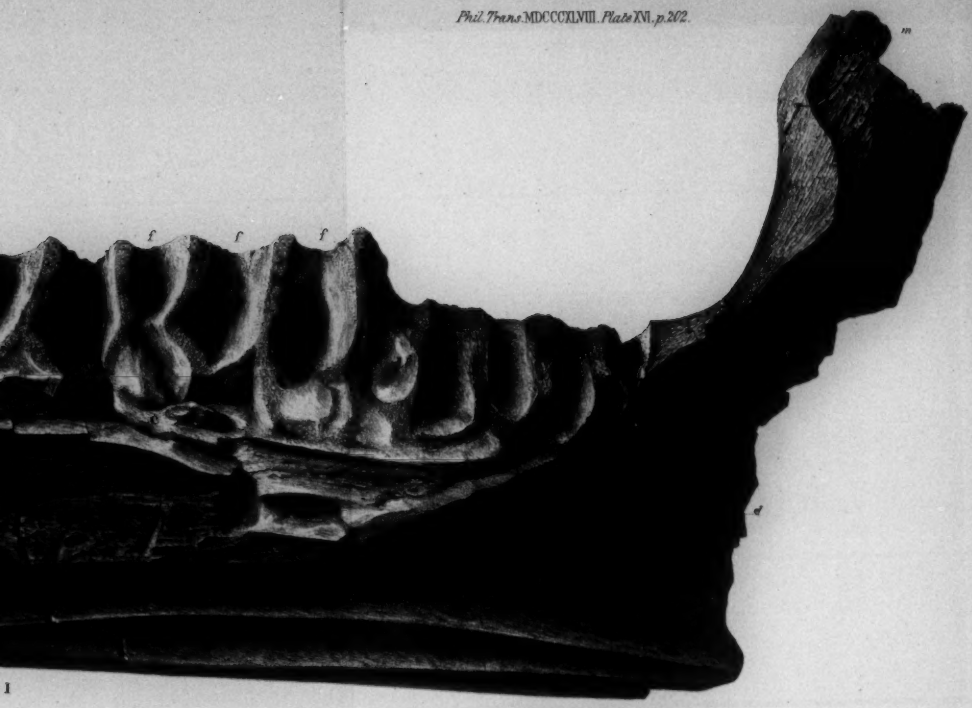
I

II

Dinkel. del. et lith.

The anterior part of the right side
of the Iguanodon Mantelli;

Fig.1. Inner or nasal aspect. Fig.2. Oblique



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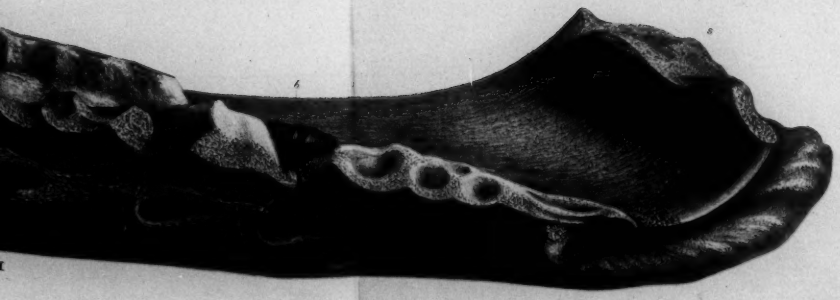
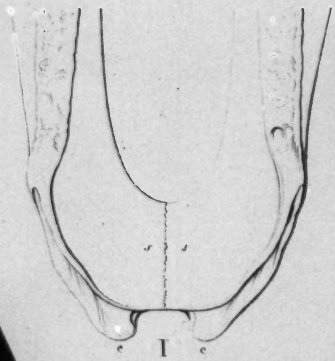


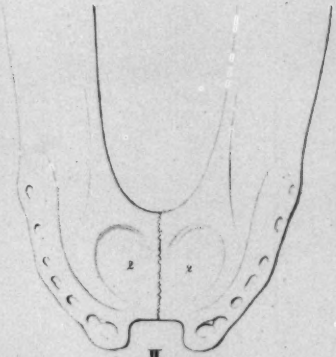
I

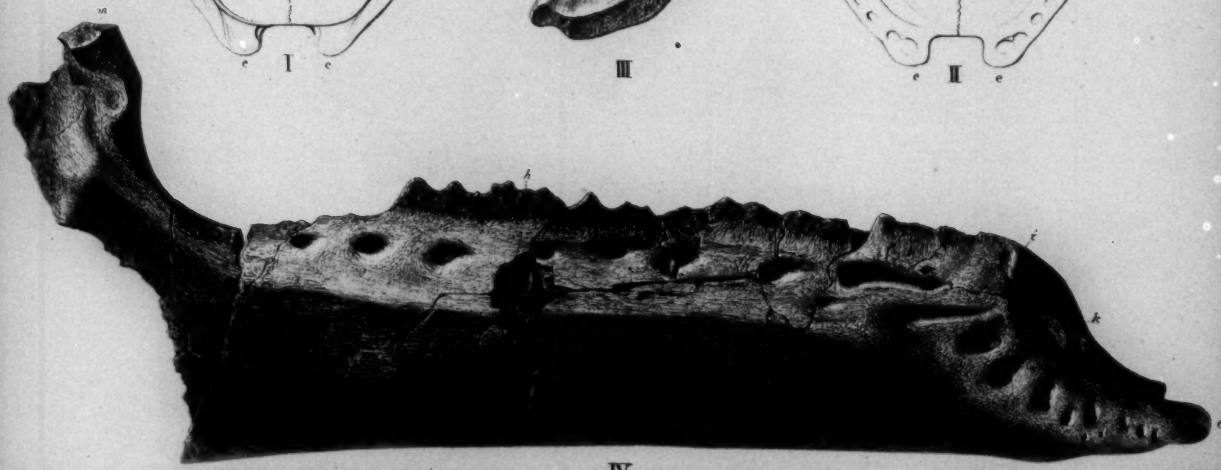
...rde of the Lower Jaw
...ll; from Tilgate Forest.
...tique external view.

Printed by J. Basire

FRANKLIN
INSTITUTE
LIBRARY







Dinkel del. et lith.

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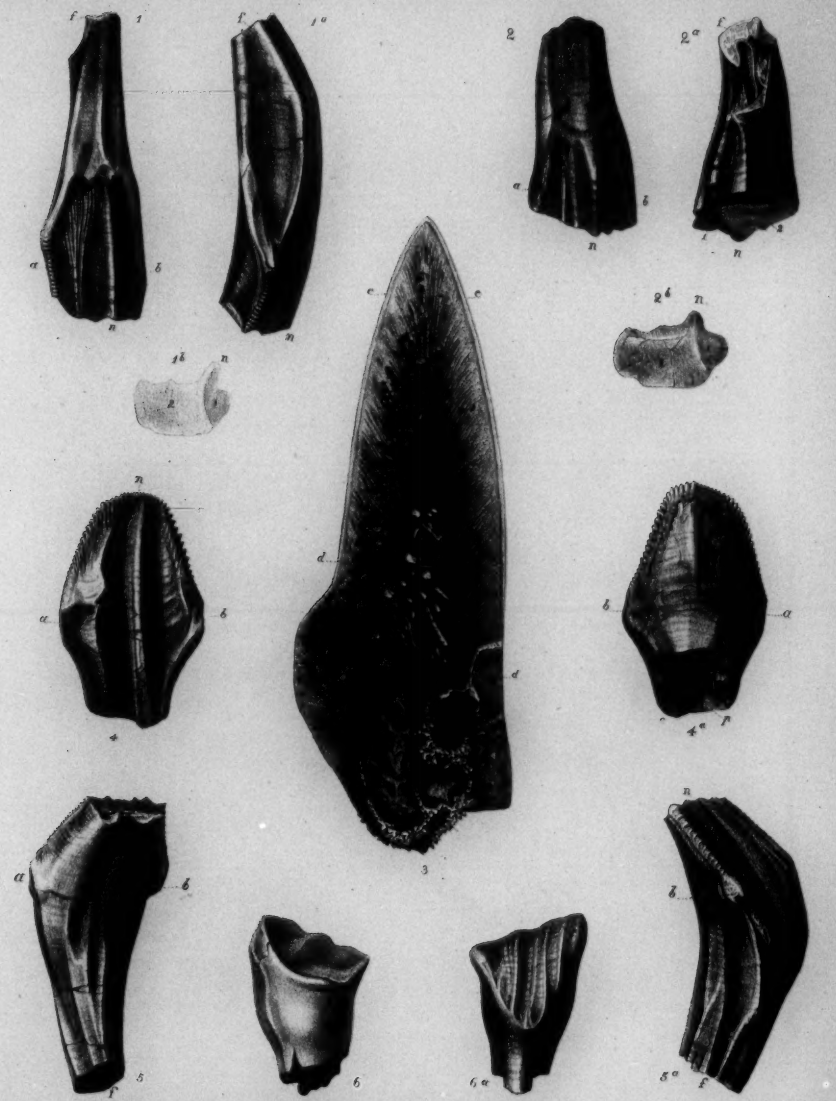

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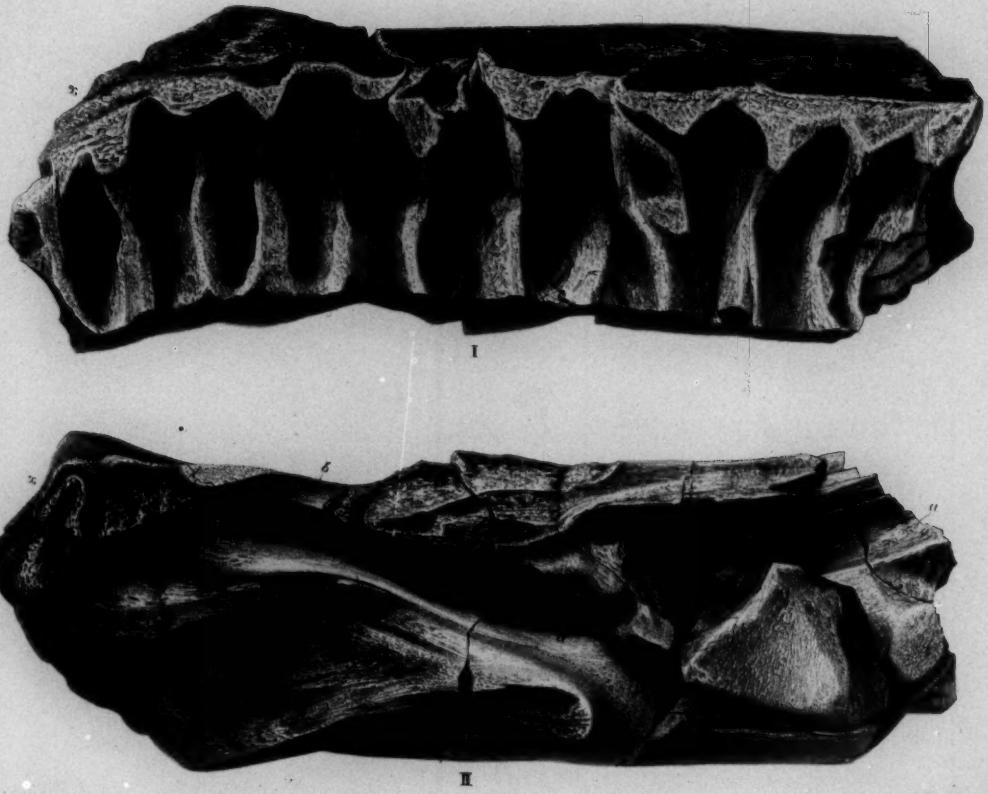
Teeth of the Iguanodon



Dinkel del. et lith.

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Portion of the Upper Jaw of the Iguanodon.